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Flight Simulator Evaluation of a Novel Display to Minimize the Risks of Spatial Disorientation

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A novel instrument display designed to reduce cognitive workload and improve accuracy of flight and recovery from a disorienting episode was tested against flight with standard instruments in a UH-60 dynamic helicopter simulator. Sixteen non-UH-60 rated pilots flew a standard instrument profile and recovered from a series of unusual attitudes both with and without a secondary task. Results from all aspects of the assessment proved the benefits of the new display. Not only was there evidence of enhanced flight control, but also an improved performance on a secondary task (auditory tone identification), and reduced control input errors. Evidence from analysis of the secondary task scores showed that cognitive workload was reduced when using the novel display compared to the standard instruments. The display should be further developed to make it possible to utilize it in a head-up display or other night vision device. It should also be developed to include the capability to display hover information and an instrument landing system. Future testing should be carried out in real flight.

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Introduction

It has long been known that humans cannot maintain straight and level flight in the absence of visual cues (Anderson, 1919). It has also long been known that not only do the human organs of balance fail to give sufficient cues for accurate perception of position or motion during aviation, but may also give erroneous cues (for overviews see Guedry, 1974 and Benson, 1978). Historically, there has been a tendency to assume that plentiful visual cues can override these misleading somatic sensations - but this is not necessarily so; for example, the reflex linkage between vestibular cues and the direction of vision may itself lead to visual aberrations such as the oculogravic illusion. Even if vision always overrode somatic sensation, vision itself is prone to illusions based on perspective, relative size, shape, color, motion, false horizons, and so forth. In other words, embedded in the many correct cues that aircrew normally receive during flight are a proportion of misleading cues. When something happens to reduce the number or quality of the correct cues, or if the misleading cues are given preference, the pilot becomes disorientated. A variety of factors such as flight conditions and state of mind or health may contribute to an episode of spatial disorientation (SD). It is logical to suspect that there is a particular risk associated with the poor quality of visual cues generated by night vision systems, including night vision goggles (NVGs) and forward looking infrared (FLIR) (Rash et al., 1990; Crowley, 1991; Durnford, 1992). Use of these systems has increased rapidly in the last few years.

The standard countermeasure for SD has always been to "get onto instruments." Instrument flying itself is a more difficult task than flying by external visual cues because it makes greater demands on mental resources and is thus more susceptible to impairment by task load and disorientation stress. Present day helicopter instrument panels are derived from fixed wing aircraft and are designed to provide information about forward flight. They do not give reliable information about hovering. There are five standard aircraft parameters that must be monitored and integrated and some aircrew have difficulty doing this even during routine instrument flight. The "panic" associated with SD makes reading and understanding five separate instruments particularly difficult. If the five parameters (aircraft attitude, airspeed, altitude, rate of climb or descent, and aircraft heading) were to be integrated into one simple display requiring little cognitive effort for comprehension it might facilitate recovery from SD - and may make the pilot less likely to be disorientated in the first place.

Under the traditional instrument display system, the pilot has to react continually to the aircraft orientation and respond accordingly. With the new concept the pilot would "select" specific orientation parameters (such as altitude and heading) and then follow a simple tracking task which would ensure that those parameters were maintained (or, if necessary, recovered). This has the added benefit of removing altogether the cognitive workload associated with interpreting the information from the five parameters into a mental "picture" of aircraft attitude and flight path. Unlike a flight director, the instrument would present information to the pilot in a simple and integrated format. The pilot could at any time check any parameter he wished (for example,

altitude or airspeed), but he would be freed from the requirement to continually monitor these parameters to maintain stable flight.

SD is a major source of attrition particularly in military helicopter flying. Recent reports (Durnford et al., 1995) estimated that 32 percent of Class A through C Army helicopter accidents involved SD. Many of these accidents would occur regardless of the instrument display in use, since the aircrew are simply not looking at the instruments. However, there are a number of accidents which involve the classically disorientating conditions of inadvertent entry to instrument meteorological conditions (IMC), whiteout or brownout, and which might be amenable to improved instrument displays. These particular accidents represent some 25 percent of U.S. Army rotary-wing SD accidents, although they constitute a considerably higher proportion in other groups such as general aviation rotary-wing accidents (Adams, 1989). In addition to these accidents, there are those in which an easily understood instrument display may prevent the initial circumstances leading to disaster by either providing an easy source of information against which aircrew might check their progress, or by providing a simple symbology which could be superimposed upon external views (as in a head-up display [HUD]).

In their preliminary work, Durnford and DeRoche (1995) provided strong evidence that the concepts behind the new display are workable, and that the new display would make recovery from unusual attitudes (and quite probably instrument flying) easier than when using the standard panel. In their study, however, there were limitations in the experimental design caused by hardware and software difficulties.

This paper describes the results of an experiment in a dynamic helicopter flight simulator to test the two hypotheses:

> During instrument flying, the novel display permits more accurate maintenance of flight parameters than the standard display.
>
> During recovery from unusual attitudes, the novel display permits faster and more accurate reestablishment of flight parameters than the standard display.

Details of the novel display

Although the original novel display was described in detail by Durnford and DeRoche (1995), modifications have been made prior to this experiment. Its design and concept of operation are therefore repeated below. Figure 1 is a photograph of the display used in this experiment and figure 2 an illustration of a subject using the display to fly the simulator. Figures 3 through 8 are diagrams illustrating the various modes of operation and are referenced in the text below.

The central field of the display consists of a series of squares (themselves arranged in a square) and a small triangle. The triangle moves across the squares depending on aircraft speed and heading. (The x axis represents heading and the y axis speed.) Movement of the triangle along these axes is a derivative of the "orientation" functions of pitch and roll since airspeed depends on pitch inputs and heading on roll inputs.

Fore and aft cyclic movements are used to maintain the desired aircraft speed by steering the triangle to the midline on the x axis. Lateral cyclic movements do the same for the heading using the y axis. Thus, if the triangle is kept in the central box, the aircraft will remain steady on both the desired speed and heading.

Altitude is color coded - the triangle maintains a green color if the altitude is +/- 20 feet of the desired parameter, a red color if it is low, and an amber color if it is high. The "altimeter" to the right of the squares reinforces height information by showing the specific altitude (in digital readout form) as well as the difference between the actual altitude and the desired altitude by means of a color coded ribbon. There is a box displaying the desired (set) altitude and another showing the pressure setting. The vertical speed indicator (VSI) on the left of the squares acts in much the same way as the color coded tape display of the altimeter. It is placed on the left because it responds to control inputs from the collective lever in the pilot's left hand.

The compass tape across the top gives the actual heading and the boxes below it, the desired (set) and actual heading. Airspeed is shown below the central squares as a digital readout of desired (set) and actual aircraft speed.

The novel display enables the pilot to specify particular parameters, such as airspeed, altitude and heading, and then match his control inputs to a simple integrated display so that the parameters are easily maintained or regained. The original design aim of the display was to provide an easy source of information for reorientation during episodes of disorientation, but the display also provides an adequate source of information for standard instrument flight. The pilot can check any flight parameter at any time but is freed from the requirement to continually monitor them to maintain stable flight. In essence, maintaining orientation using the novel display replaces a high level cognitive task with a comparatively low level tracking task.

The essential aim when flying the display is to keep the triangle in the center box. In this way the parameters for heading and airspeed that have been set, will be maintained or regained by moving the cyclic. Aircraft altitude is regulated by the collective lever. The display has several modes to enable accurate maintenance of flight parameters. These are described in the text below.

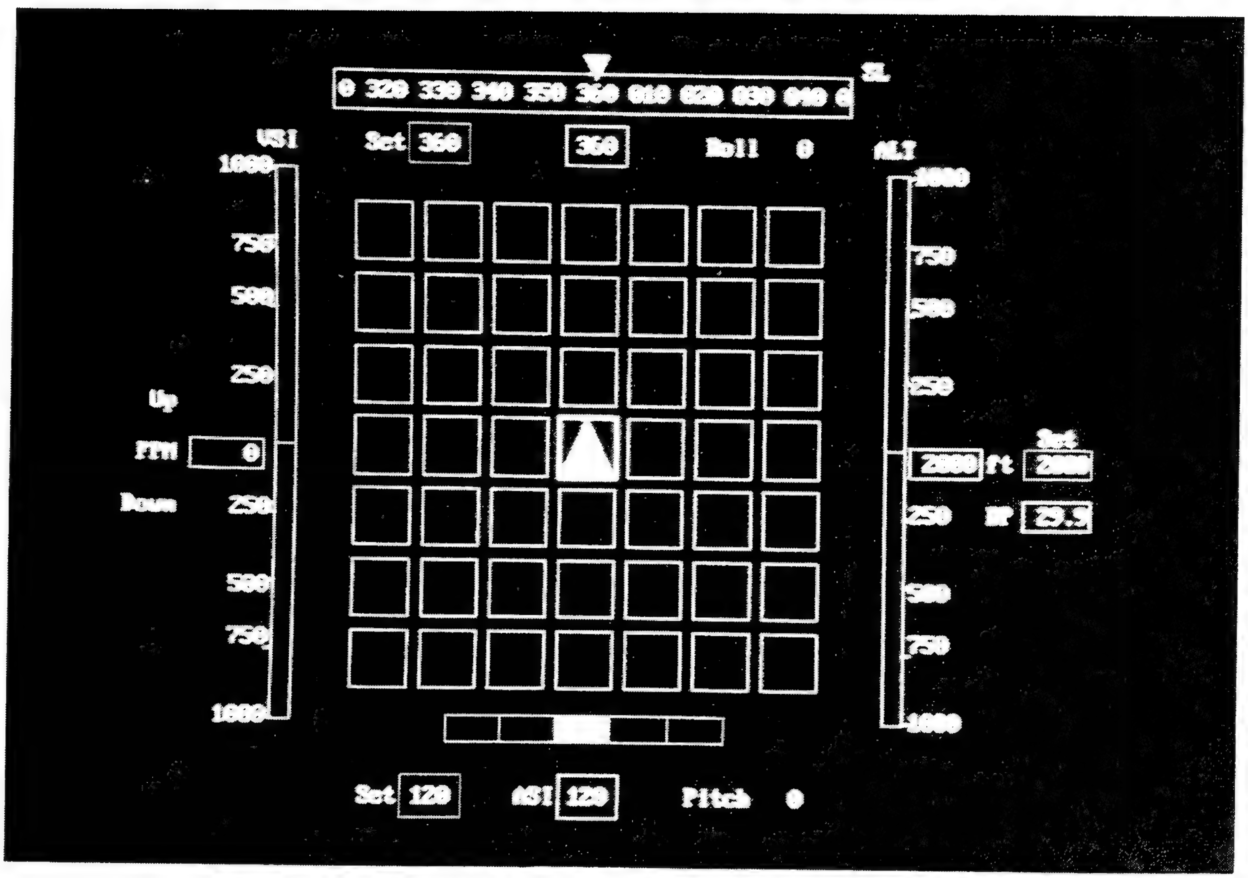


Figure 1. Photograph of the novel display.

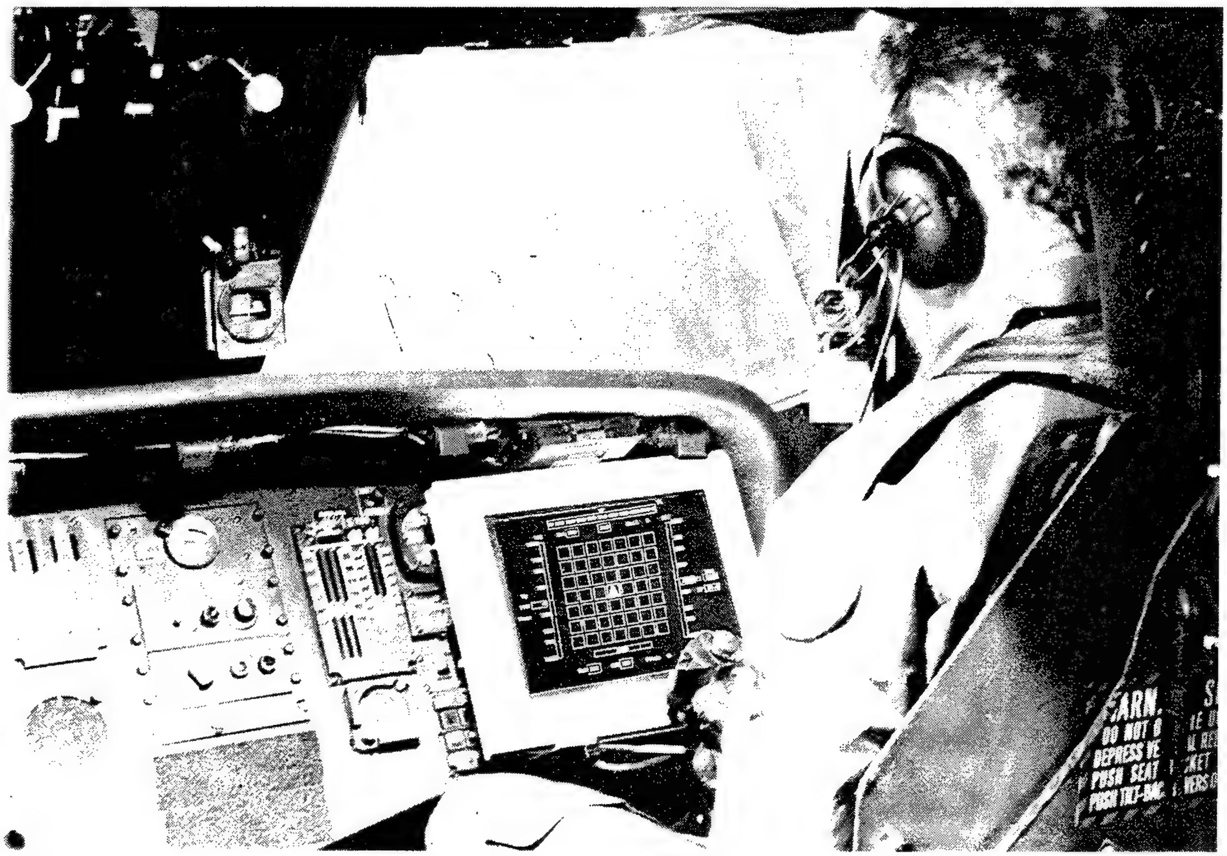


Figure 2. Photograph of subject flying the novel display in the UH-60 simulator.

Straight and level mode

In straight and level mode, if the collective pitch setting is correct, heading and airspeed will be maintained or return to their set parameters by keeping the triangle in the center box. This is the default mode. Any deviation from the set parameters will be obvious, and the control movement required to regain orientation is immediately apparent.

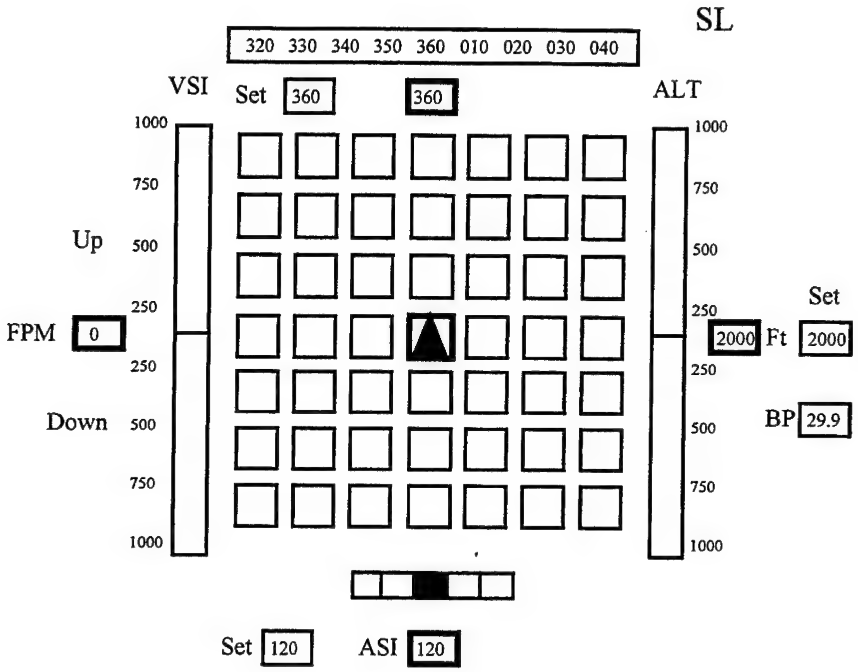


Figure 3. Novel display in straight and level mode.

Turns

At the beginning of the right standard rate turn (3 degrees per second) example shown in figure 4, the new heading is set and the triangle is placed off to one side (to the left in this case for a right turn). Movement of the cyclic to place the triangle in the center sets an appropriate roll angle to maintain the turn rate for that airspeed. At approximately 20 degrees from the new heading, the display algorithm starts reducing the required angle of bank, and so movement of the triangle in the opposite direction prompts the pilot to start applying right cyclic control to roll out of the turn.

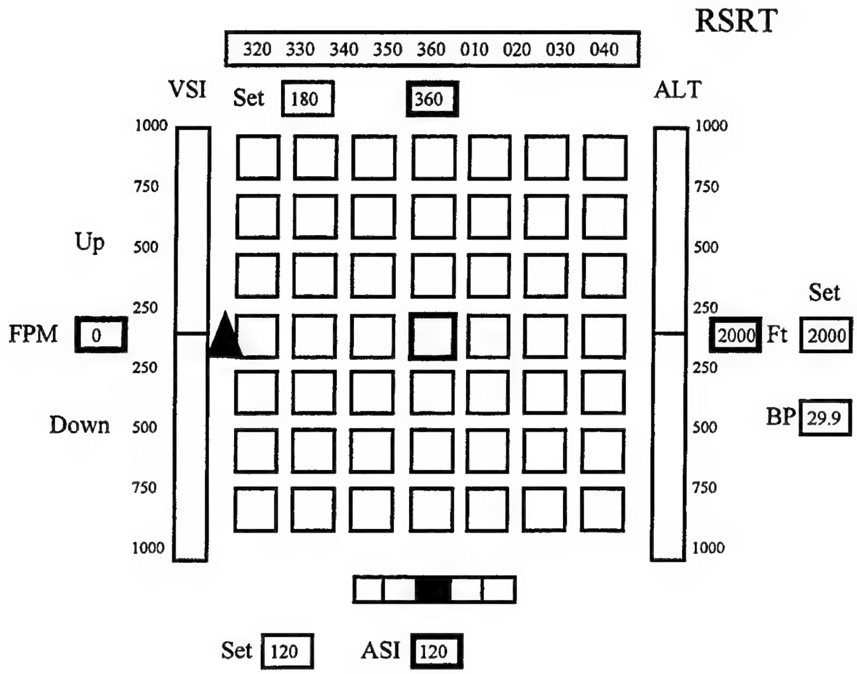


Figure 4. Novel display in turn mode.

Climbs and descents

At the start of a constant heading climb (figure 5), the altitude to be achieved is set so both the altimeter ribbon and the triangle will be indicating "too low." While maintaining the triangle in the center square (to maintain heading and airspeed), power is added so that the vertical speed ribbon indicates the desired climb rate (figure 6). The precise vertical speed is shown in the VSI box. A similar arrangement of the parameters occurs during a descent, and both turns and vertical changes can easily be combined, for example in a left descending turn (figure 7).

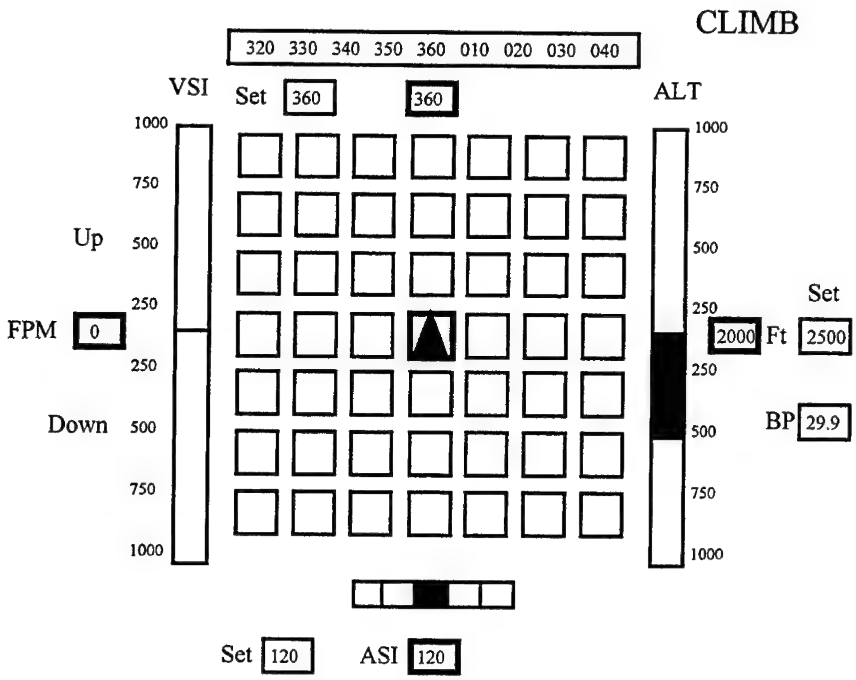


Figure 5. Novel display in climb mode (beginning of maneuver).

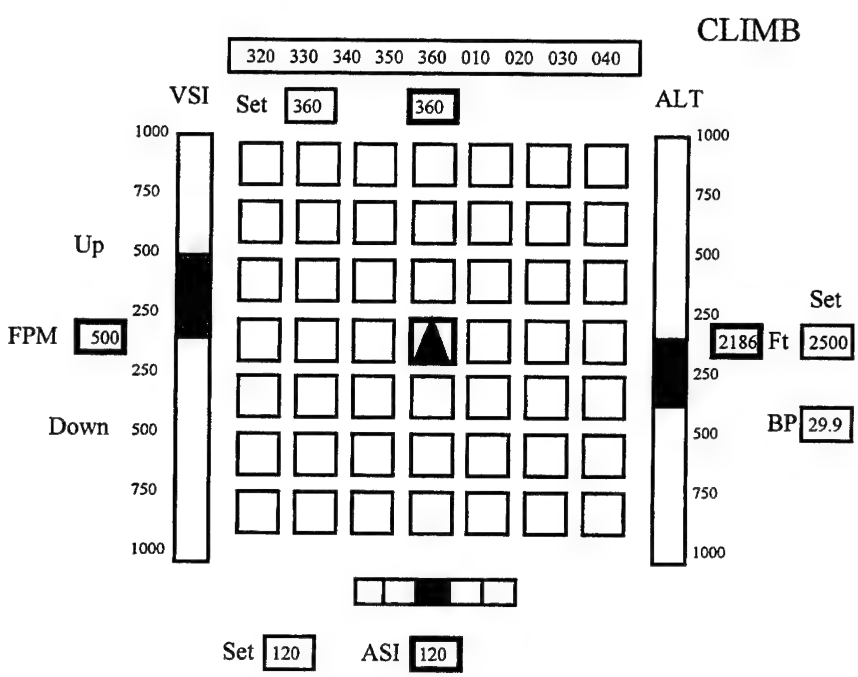


Figure 6. Novel display in climb mode (during maneuver).

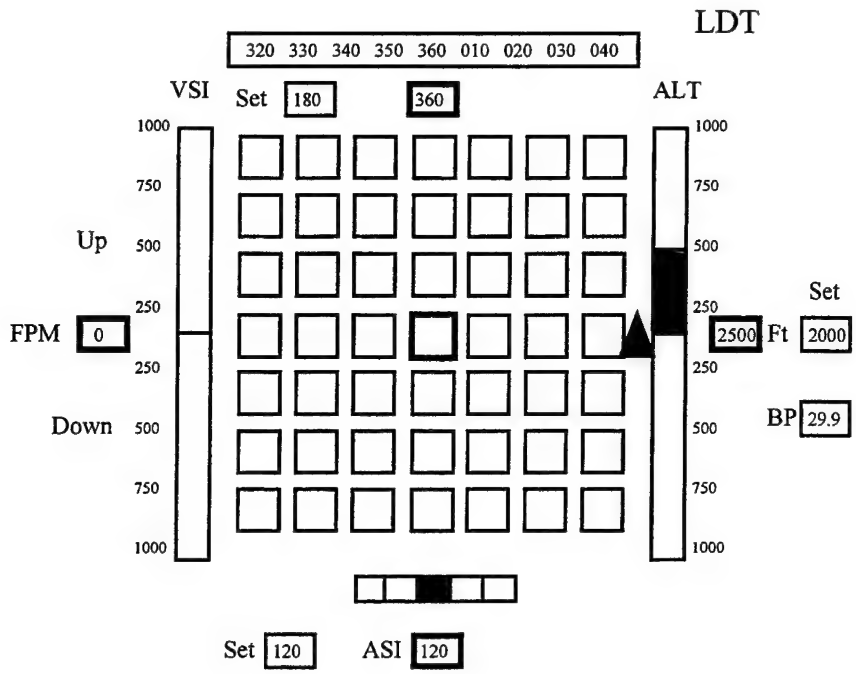


Figure 7. Novel display in left descending turn mode.

Unusual attitude recovery

The mode of use of the display when recovering from unusual attitudes (UAs) during this experiment was slightly modified. The simulator was programmed to "fly" into an unusual attitude while the subject pilot closed his eyes and released the controls. This is a standard manner of training used by instructor pilots in actual aircraft. The immediate action on recovery from UAs is to achieve wings level and pitch level (appropriate to the current airspeed), and then recover to the original airspeed, heading and altitude. It was therefore decided to maintain this procedure for the purposes of this assessment, so that a direct comparison between the two displays could be made. At the initiation of recovery from each UA, the normally integrated factors of pitch and airspeed, and roll angle and heading error were "decoupled." In this way the immediate action as referred above could be achieved by placing the triangle in the central square. Had they not been decoupled, placing the triangle in the central square would have immediately induced both a roll angle in the opposite direction to correct the heading error, and a pitch angle opposite to that present at the beginning of the recovery sequence. Although it has been demonstrated in the simulator during the preliminary development, that recovery from UAs is most effective when using the novel display in its default (straight and level mode), the experiment would have been biased in favor of the novel display if this modification had not been made. In order to alert the subject to this specific mode, the set boxes of heading and airspeed were hatched (figure 8). Once wings and pitch level had been achieved as described

above, the subject pressed a button on the collective lever which was programmed to restore the set values of heading and airspeed, and once again integrate roll angle with heading error, and pitch with airspeed. Recovery to the original parameters could now occur in the same fashion as departure from straight and level flight. Dependent on the type of aircraft, this modification to the display will require further assessment if the display is to be incorporated into an actual cockpit.

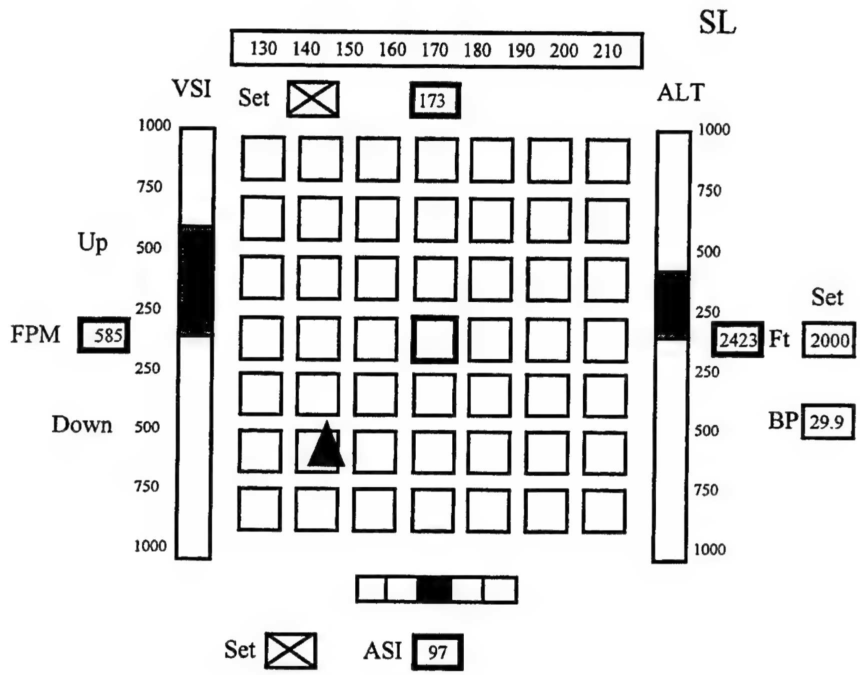


Figure 8. Novel display in experimental unusual attitude mode.

Methods

Whereas the original display software was written using Designers Workbench on a Silicon Graphics computer, software interface problems with the UH-60 simulator necessitated rewriting the program in Quick Basic on an IBM compatible computer. The novel display was tested against the standard flight instrument display in the UH-60 flight simulator to determine which display produced the "best" flight performance from aircrew subjects under conditions of simulated instrument flight and during recovery from unusual attitudes. The two display formats were tested both with and without a secondary task.

Subjects

Sixteen male non-UH-60 rated pilots volunteered to participate. Female pilots were not excluded from the study but none volunteered. Each subject was in normal health and free from medication. All were easily able to hear and identify the low and high tones of the secondary task. Various personal details were gathered, and subjects were given both a written and an oral brief. All signed volunteer consent forms. These individuals were between the ages of 25 and 48 years, with a mean age of 34.5 years (SD = 8.22). Total flight hours ranged from 141 to 7600 hours, with a mean of 2242 hours (SD = 2495), and instrument flight hours ranged from 35 to 1500 hours, with a mean of 261 hours (SD = 379).

Apparatus

The UH-60 flight simulator

All simulator flights were conducted at the U.S. Army Aeromedical Research Laboratory (USAARL), using the UH-60 research flight simulator. This motion-based system includes an operational crew station and a computer-generated visual display which was set for standard daytime instrument flight, and a multi-channel data acquisition system.

Flight data were acquired on a VAX 11/780 interfaced to a Perkin-Elmer digital computer which controlled the UH-60 flight simulator. This system monitored several aspects of simulator control, including heading, airspeed, altitude, roll angle, turn rate and vertical speed.

When being used, the novel display was projected on a PIXCELVISION® flat panel which was mounted on the instrument panel covering the standard flight instruments of the right-hand crew station.

Instrument flying task

The flight performance evaluations required subjects to perform the maneuvers listed in table 1. This profile is a standard and validated instrument flight task developed by USAARL, and comprises non-tactical, upper-air work in which the subject was required to perform precision maneuvers based upon instrument information. The first group of maneuvers was flown with the automatic flight control system (AFCS) trim engaged (or ON), and the second group was flown with the AFCS trim disengaged (or OFF). The AFCS trim system enhances the static stability and handling qualities of the aircraft/simulator.

There were 15 maneuvers in the flight profile. These consisted of four straight-and-levels (one with AFCS OFF), two left standard-rate turns (one with AFCS OFF), three right standard-rate turns (one with AFCS OFF), two standard-rate climbs, three standard-rate descents (all with AFCS OFF), and one left descending turn (with AFCS OFF).

For each of these maneuvers, the subjects were required to maintain a constant airspeed of 120 knots, but the specific targets for other parameters such as heading, altitude, roll, etc., depended on the maneuver being flown. Subjects were instructed to attempt to maintain appropriate ideal flight parameters during each maneuver. For instance, during the standard-rate turns, subjects were told to fly at a specific altitude (e.g., 2000 feet for the first left turn), and they were evaluated on how precisely they were able to maintain that altitude throughout the maneuver. Also, during the turns, subjects were evaluated on how precisely they maintained a standard roll angle of 19 degrees, and a standard turn rate of 3 degrees per second. The specific maneuvers, the measures examined, and the ideal parameters for each are presented in tables 2 and 3.

The instrument flying profile lasted approximately 25 minutes, and during each profile, performance was measured using the simulator's computerized performance monitoring system described earlier. During each flight, the simulator operator who was also a UH-60 pilot was present to instruct the subject and ensure the proper sequencing and timing of all flight maneuvers.

Flight performance data for each maneuver were trimmed so that data from the start and end of the maneuver were excluded from the analysis. This was necessary because data during the establishment or end of the maneuver were not representative of the parameters to be measured, e.g., while a subject was rolling the simulator into and out of a standard rate turn, the roll angle varied between 0 degrees and 19 degrees. Root mean square (RMS) errors were then calculated for each measure within each maneuver to express how well subjects maintained specific headings, altitudes, airspeeds, etc. The formula for calculating RMS error is essentially the same as the one for calculating a standard deviation, with the exception that RMS errors reflect the amount of deviation from an ideal value rather than from a mean. The RMS errors were transformed to their log natural values prior to analysis to minimize the impact of extreme values.

Table 1.
Instrument flight profile.

Maneuver	Description
1. Straight & level (SL1)	Maintain heading 360°, airspeed 120 kts, altitude 2000 ft AMSL for 1 min.
2. Left standard rate turn (LSRT1)	Perform 360° left standard rate turn maintaining airspeed and altitude.
3. Straight & level (SL2)	Maintain heading 360°, airspeed 120 kts, and altitude 2000 ft AMSL for 1 min.
4. Climb (Cl 1)	Climb from 2000 ft to 2500 ft while maintaining heading and airspeed.
5. Right standard rate turn (RSRT 1)	Perform 180° right standard rate turn maintaining airspeed and altitude.
6. Straight & level (SL3)	Maintain heading 180°, airspeed 120 kts, and altitude 2500 ft AMSL for 1 min.
7. Right standard rate turn (RSRT 2)	Perform 180° right standard rate turn maintaining airspeed and altitude.
8. Climb (Cl 2)	Climb from 2500 to 3500 ft while maintaining heading and airspeed. TURN AFCS OFF
9. Descent (Desc 1)	Descend from 3500 to 3000 ft while maintaining heading and airspeed.
10. Left descending standard rate turn (LDT)	Perform 180° left standard rate turn while descending from 3000 ft to 2500 ft maintaining airspeed.
11. Descent (Desc 2)	Descend from 2500 ft to 2000 ft while maintaining heading and airspeed.
12. Left standard rate turn (LSRT 2)	Perform 180° left standard rate turn maintaining altitude and airspeed.
13. Straight & level (SL 4)	Maintain heading 360°, airspeed 120 kts, altitude 2000 ft for 2 mins.
14. Right standard rate turn (RSRT 3)	Perform 360° right standard rate turn while maintaining altitude and airspeed.
15. Descent (Desc 3)	Descend from 2000 to 1000 ft AMSL maintaining heading and airspeed

Table 2.
Instrument flight maneuvers (conducted with the AFCS ON) with parameters scored for each maneuver.

Maneuver	Duration (sec)	Parameters	Ideal values
Straight & level	60	Heading	360 degrees
		Altitude	2000 feet AMSL
		Airspeed	120 knots
		Roll	0 degrees
Left std rate turn	120	Turn rate	3 deg/sec
		Altitude	2000 feet AMSL
		Airspeed	120 knots
		Roll	19 degrees
Straight & level	60	Heading	360 degrees
		Altitude	2000 feet AMSL
		Airspeed	120 knots
		Roll	0 degrees
Climb	60	Heading	360 degrees
		Airspeed	120 knots
		Roll	0 degrees
		Rate of Climb	500 feet/min
Right std rate turn	60	Turn rate	3 deg/sec
		Altitude	2500 feet AMSL
		Airspeed	120 knots
		Roll	19 degrees
Straight & level	60	Heading	180 degrees
		Altitude	2500 feet AMSL
		Airspeed	120 knots
		Roll	0 degrees
Right std rate turn	60	Turn rate	3 deg/sec
		Altitude	2500 feet AMSL
		Airspeed	120 knots
		Roll	19 degrees
Climb	60	Heading	360 degrees
		Airspeed	120 knots
		Roll	0 degrees
		Rate of Climb	500 feet/min

Table 3.
Instrument flight maneuvers (conducted with the AFCS OFF) with parameters scored for each maneuver.

Maneuver	Duration (sec)	Parameters	Ideal values
Descent	60	Heading	360 degrees
		Airspeed	120 knots
		Roll	0 degrees
		Rate of Descent	500 feet/min
Left descending turn	60	Turn Rate	3 deg/sec
		Airspeed	120 knots
		Roll	19 degrees
		Rate of Descent	500 feet/min
Descent	60	Heading	180 degrees
		Airspeed	120 knots
		Roll	0 degrees
		Rate of Descent	500 feet/min
Left std rate turn	60	Turn rate	3 deg/sec
		Altitude	2000 feet AMSL
		Airspeed	120 knots
		Roll	19 degrees
Straight & level	120	Heading	360 degrees
		Altitude	2000 feet AMSL
		Airspeed	120 knots
		Roll	0 degrees
Right std rate turn	120	Turn rate	3 deg/sec
		Altitude	2000 feet AMSL
		Airspeed	120 knots
		Roll	19 degrees
Descent	120	Heading	360 degrees
		Airspeed	120 knots
		Roll	0 degrees
		Rate of Descent	500 feet/min

Recovery from unusual attitudes

Once the instrument flying phase was complete, the simulator was reoriented to 5000 ft AMSL, 100 knots, and heading 180 degrees. Pilots were then assessed in their ability to recover from unusual attitudes. So that each condition was repeatable for all subjects, the simulator was programmed to "fly itself" into a series of unusual attitudes. The subject sat free from the controls with his eyes closed while the simulator maneuvered itself into the unusual attitude. All maneuvers were in IMC and commenced from, and ended in balanced level flight, at 100 knots, 5000 ft altitude, heading 180 degrees with AFCS disengaged. Subjects recovered to these parameters and maintained them for 30 seconds.

With the constraint that subjects were presented initially with either UA number 1 or 2, the order of maneuvers was selected at random. The maneuvers programmed into the simulator are shown in table 4.

The subjects' recovery times were measured to wings level, pitch level, and to regaining the original flight parameters after each unusual attitude as follows:

desired airspeed (+/- 10 kts)
desired heading (+/- 10 degrees)
desired altitude (+/- 100 ft)
airspeed + heading + altitude **ALL** within tolerance
maintenance of **ALL** parameters for 30 seconds.

A computer program was also written to analyze the direction of cyclic stick movement during the first 5 seconds of recovery. In this way, any control reversal error immediately following resumption of control could be noted and quantified.

Table 4.
Unusual attitude maneuvers

Unusual attitude number	Simulator maneuver
1	Initiate right roll at a roll rate of 5 degrees per second to 30 degrees angle of bank. Hold at 30 degrees angle of bank for 10 seconds.
2	Initiate pitch nose down at 2 degrees per second to 15 degrees nose down. Hold at 15 degrees nose down for 5 seconds.
3	Initiate simultaneously: pitch nose up at 2 degrees per second to 15 degrees nose up, and increase torque at 5% per second to 65%. Hold at 15 degrees nose up and 10% torque for 5 seconds.
4	Initiate left roll at a roll rate of 5 degrees per second to 30 degrees angle of bank. Hold at 30 degrees angle of bank for 3 seconds. Then initiate simultaneously: pitch nose down at 2 degrees per second to 10 degrees nose down and decrease torque at 5% per second to 25%. Once pitch and torque setting obtained, hold for 3 seconds.
5	Initiate simultaneously: left roll at a roll rate of 10 degrees per second to 30 degrees angle of bank, pitch nose up at 3 degrees per second to 15 degrees nose up, increase in torque at 5% per second to 65%. Once pitch, roll and torque settings obtained, hold for 3 seconds.
6	Initiate simultaneously: right roll at roll rate of 10 degrees per second to 30 degrees angle of bank, and reduce torque at 10% per second to 20%. Once roll and torque setting obtained, hold for 3 seconds. Then initiate pitch nose down at 5 degrees per second to 20 degrees nose down.

Secondary task

The laptop computer that drove the novel display was programmed to produce audio tones similar to that produced by an American Computer Zero Input Tracking Analyzer (ZITA) machine. This technique has been extensively described in previous studies (see, for example, Simmons et al., 1989). The 250 millisecond tones were at 500 Hz (low) and 1000 Hz (high). The subject was required to identify the tone as high or low by pressing the appropriate button before the next tone was played. Tones were played at varying rates between 0.5 and 1 Hz. The number of total, correct and incorrect responses were used as dependent measures to assess the effect of the display on the secondary task. This task was considered to provide a significant challenge for subjects given a difficult primary task. The experiment was designed to negate any training effect from this task. Therefore, the analysis of scores should only have reflected the ease with which the subjects accomplished the primary task.

To prevent the need for the subjects to remove their hands from the aircraft controls during this experiment, the retract and extend functions of the searchlight switch on the collective lever were programmed to respond to the appropriate input (high or low tone).

Subject questionnaires

After completing all four test flights, subjects were asked to complete a questionnaire rating various factors of the new display against the standard instruments. The questionnaire is reproduced at table 5.

Training and test schedule

All the subjects were familiar with instrument flight using a standard instrument display. However, as they were not rated on a UH-60, and to minimize learning effects, they were given a period of training on the instrument flying profile and recovery from unusual attitudes during the day prior to their first experimental run. This consisted of familiarization with the UH-60 standard flight instrument layout and then three flights of the experimental protocol. Because of its unique nature, training on the novel display commenced with familiarization on the static simulator used in Durnford and DeRoche's original experiment (1995). Once the subjects understood the format and function of the display, training in the UH-60 simulator was as for the standard instrument display. There was no requirement for the subjects to be familiar with the UH-60 engine monitoring instruments (except transmission torque) or avionics. The subjects were introduced to the secondary task early in the general phase of training and practiced it during the simulator practice sessions. The subjects were told that they would be scored on all parts of the experiment but they should concentrate on the primary task, flying the simulator. The test schedule is shown at table 6.

In order to achieve a balanced design while negating the influence of time of day, there were four possible sequences for exposure to both display conditions with and without the secondary task. These are shown in table 7. The 16 subjects were randomly assigned to create equal groups for each sequence.

Table 5.
Subject questionnaire.

1. PLEASE RATE THE EASE OF USE OF TWO DISPLAYS BY CHECKING THE APPROPRIATE BOXES BELOW ACCORDING TO THE FOLLOWING CODE:

1 = VERY DIFFICULT
2 = DIFFICULT
3 = ADEQUATE
4 = EASY
5 = VERY EASY

NOVEL DISPLAY 1	2	3	4	5		STANDARD DISPLAY 1	2	3	4	5
					PRESENTATION OF ALTITUDE INFORMATION					
					PRESENTATION OF AIRSPEED INFORMATION					
					PRESENTATION OF CLIMB/DESCENT INFORMATION					
					PRESENTATION OF HEADING INFORMATION					
					PRESENTATION OF ANGLE OF BANK INFORMATION					
					PRESENTATION OF PITCH INFORMATION					
					WORKLOAD REQUIRED TO FLY STANDARD MANEUVERS					
					WORKLOAD REQUIRED TO RECOVER FROM UNUSUAL ATTITUDES					
					EASE WITH WHICH ONE CAN FLY ACCURATELY					
					OVERALL EASE OF USE					
					EASE OF LEARNING TO USE THE DISPLAY					

2. WHAT, IN YOUR VIEW, WERE THE GOOD POINTS OF THE NOVEL DISPLAY?

3. WHAT, IN YOUR VIEW, WERE THE BAD POINTS OF THE NOVEL DISPLAY?

4. WHAT OTHER POINTS WOULD YOU LIKE TO RAISE?

Simulator sickness questionnaire

As it is known (Gower and Fowkles, 1989) that flight in the UH-60 simulator, particularly by non-rated aviators, may provoke simulator sickness, the subjects were monitored for this problem. As well as direct observation by the principal investigator or medical monitor, the subjects were asked to complete a copy of the simulator sickness questionnaires designed by Lane and Kennedy (1988) before and after each simulator test flight.

Statistical methods

Statistical analysis of various factors was conducted using the Analysis of Variance (ANOVA) and Basic Statistics modules of STATSOFT STATISTICA®. The results are presented in tables 8 through 18 and in graphical form as figures at the end of this report.

Table 6.
Training and test schedule.

Two subjects (referred to here as subject Y and subject Z) were tested within a week.
Days 1, 2 and 3 were consecutive weekdays.

Day	Time	Subject Y	Subject Z
1	0730	Report to USAARL	Briefing on experiment
1	0830 - 1000	Training on novel display (static simulator) and training on secondary task	Familiarization with UH-60 simulator to include practice flights with standard display
1	1000 - 1130	Familiarization with UH-60 simulator to include practice flights with standard display	Training on novel display (static simulator) and training on secondary task
1	1300 - 1430	Practice flights in simulator with novel display	FREE
1	1430 - 1600	FREE	Practice flights in simulator with novel display
1	1600	Debrief Day 1	Brief for days 2 and 3.

2	0830	Test schedule (as design)	
2	1000	Debrief	Test schedule (as design)
2	1300	Test schedule (as design)	Debrief
2	1430	Debrief	Test schedule (as design)
2	1600		Debrief

3	0830	Test schedule (as design)	
3	1000	Debrief	Test schedule (as design)
3	1300	Test schedule (as design)	Debrief
3	1430	Debrief Depart USAARL	Test schedule (as design)
3	1600		Debrief Depart USAARL

Table 7.
Experimental design matrix.

Key:
std disp = STANDARD DISPLAY
nov disp = NOVEL DISPLAY
sec task = SECONDARY TASK

Sequence	Day 2		Day 3	
	morning	**afternoon**	**morning**	**afternoon**
A	std disp sec task	nov disp sec task	std disp	nov disp
B	nov dis sec task	std disp sec task	nov disp	std disp
C	std disp	nov disp	std disp sec task	nov dis sec task
D	nov disp	std disp	nov dis sec task	std disp sec task

Results

General

The objective of this research was to determine whether the novel instrument display format developed by Durnford and DeRoche (1995) will reduce the risk of spatial disorientation or improve the ability of aircrew to recover from unusual attitudes in a flight simulator. To achieve this goal, the data from flight and secondary task performance were analyzed to compare the magnitude of the effect of the novel display relative to the standard flight instruments.

Instrument Flight Performance

ANOVA was performed on the transformed RMS errors. The first two within-subjects factors were instrument display (novel vs. standard) and secondary task (presence or absence). Maneuvers which were flown more than once during each flight included a third factor designated iteration. Level turns, whether they were right or left, were treated as iterations of the same maneuver. Significant main effects and interactions were followed by appropriate post hoc analyses consisting of simple effects and/or contrasts to pinpoint the location of noteworthy differences. For this study, only the main effect of display was of relevance, and therefore the main effect of the secondary task is not reported. Similarly, the only 2-way interaction of interest was that between the display and secondary task. The data were analyzed first by examining the various maneuvers for both AFCS on and off conditions, and then by examining particular flight parameters throughout the profile. All analyses were performed treating subject number as a random variable. Each analysis is presented in the sections below. A p value of 0.05 was regarded as significant in all analyses. F and p values are shown in the comprehensive series of figures and so will not be repeated in the text.

Analysis by maneuver

Straight and level maneuvers

AFCS ON. The results of ANOVA are presented in table 8 and figures 9 through 12. There was only one significant 3-way interaction between display, secondary task and iteration. This was for heading control. Analysis of simple effects showed this was due to better performance using the novel display during SL 2 when the secondary task was present. There were significant 2-way interactions between the display type and secondary task on altitude and heading control which were attributable to differences between the displays in favor of the novel display during SL 2 and 3. By treating each iteration of the maneuver as a repeated measure, there were highly significant main effects for display for all parameters measured. In every case, performance using the novel display was superior to performance using standard instruments.

Table 8.
Significance (p) values for straight and level maneuvers, AFCS ON.

Parameter	Display effect	Display vs. secondary task	Display vs. secondary task vs. iteration	*Associated Figures*
airspeed	0.0000	0.5844	0.6941	*9*
roll angle	0.0000	0.1705	0.0780	*10*
altitude	0.0000	0.0107	0.1544	*11*
heading	0.0000	0.0073	0.0003	*12*

shaded cells are non-significant

AFCS OFF. The results of ANOVA are presented in table 9 and figures 13 through 16. There was only one iteration of this maneuver and therefore no 3-way interactions. There was only one significant 2-way interaction between the display type and secondary task. This was for airspeed control. There was also a highly significant main effect for display for all parameters measured. In every case, performance using the novel display was superior to performance using standard instruments.

Table 9.
Significance (p) values for straight and level maneuvers, AFCS OFF.

Parameter	Display effect	Display vs. secondary task	Display vs. secondary task vs. iteration	*Associated Figures*
airspeed	0.0000	0.0128	____	*13*
roll angle	0.0000	0.0598	____	*14*
altitude	0.0001	0.8231	____	*15*
heading	0.0000	0.3512	____	*16*

shaded cells are non-significant

Level turn maneuvers

As stated above, level turns were treated as iterations of the same maneuver, whether they were right or left. This was considered an acceptable grouping as the skill required is identical, and the statistical power of the analysis was thus enhanced.

AFCS ON. The results of ANOVA are presented in table 10 and figures 17 through 20. There was no significant 3-way interaction between display, secondary task and iteration. There were significant 2-way interactions between the display type and secondary task on airspeed, altitude and turn rate, which were attributable to better performance when using the novel display compared to the standard instruments when the secondary task was present. There were were highly significant main effects for display for all parameters measured. In every case, performance using the novel display was superior to performance using standard instruments.

Table 10.
Significance (p) values for level turn maneuvers, AFCS ON.

Parameter	Display effect	Display vs. secondary task	Display vs. secondary task vs. iteration	*Associated Figures*
airspeed	0.0000	0.0022	0.2515	*17*
roll angle	0.0000	0.0783	0.4823	*18*
altitude	0.0000	0.0019	0.2417	*19*
turn rate	0.0000	0.0214	0.7642	*20*

shaded cells are non-significant

AFCS OFF. The results of ANOVA are presented in table 11 and figures 21 through 24. There was no significant 3-way interaction between display, secondary task and iteration. There were significant 2-way interactions between the display type and secondary task on roll angle and turn rate which were attributable to better performance when using the novel display compared to the standard instruments when the secondary task was present. There were were highly significant main effects for display for all parameters measured. In every case, performance using the novel display was superior to performance using standard instruments.

Table 11.
Significance (p) values for level turn maneuvers, AFCS OFF.

Parameter	Display effect	Display vs. secondary task	Display vs. secondary task vs. iteration	*Associated Figures*
airspeed	0.0000	0.8207	0.5920	*21*
roll angle	0.0000	0.0174	0.8698	*22*
altitude	0.0000	0.5029	0.5469	*23*
turn rate	0.0000	0.0271	0.6885	*24*

shaded cells are non-significant

Climb maneuvers

Climbs were only performed with the AFCS engaged. The results of ANOVA are presented in table 12 and figures 25 through 28. There was only one significant 3-way interaction between display, secondary task and iteration. This was for airspeed control. Analysis of simple effects showed that this was due to better performance using the novel display compared to the standard instruments during climb 2 when the secondary task was present. There were no significant 2-way interactions between the display type and secondary task. There were highly significant main effects for display for all parameters measured. In every case, performance using the novel display was superior to performance using standard instruments.

Table 12.
Significance (p) values for climb maneuvers, AFCS ON.

Parameter	Display effect	Display vs. secondary task	Display vs. secondary task vs. iteration	*Associated Figures*
airspeed	0.0000	0.6137	0.0449	*25*
roll angle	0.0000	0.7901	0.1017	*26*
heading	0.0000	0.1930	0.1971	*27*
rate of climb	0.0000	0.8689	0.4748	*28*

shaded cells are non-significant

Descent maneuvers

Descents were only performed with the AFCS disengaged. The results of ANOVA are presented in table 13 and figures 29 to 32. There was neither a significant 3-way interaction between display, secondary task and iteration, nor a 2-way interaction between the display type and secondary task. There were highly significant main effects for display for all parameters measured. In every case, performance using the novel display was superior to performance using standard instruments.

Table 13.

Significance (p) values for descent maneuvers, AFCS OFF.

Parameter	Display effect	Display vs. secondary task	Display vs. secondary task vs. iteration	*Associated Figures*
airspeed	0.0000	0.0891	0.5613	*29*
roll angle	0.0000	0.3576	0.2429	*30*
heading	0.0000	0.4800	0.6804	*31*
rate of descent	0.0000	0.6133	0.0541	*32*

shaded cells are non-significant

Left descending turn maneuver

There was only one maneuver of this type, performed with the AFCS disengaged. The results of ANOVA are presented in table 14 and figures 33 through 36. There were no significant 2-way interactions between the display type and secondary task, but for each parameter there was a highly significant main effect for display. Performance using the novel display was superior to performance using standard instruments.

Table 14.
Significance (p) values for left descending turn maneuver, AFCS OFF.

Parameter	Display effect	Display vs. secondary task	Display vs. secondary task vs. iteration	*Associated Figures*
airspeed	0.0000	0.0898	_____	*33*
roll angle	0.0000	0.3224	_____	*34*
turn rate	0.0000	0.2800	_____	*35*
rate of descent	0.0000	0.9452	_____	*36*

shaded cells are non-significant

Analysis by maneuver

For this analysis, the RMS errors for each parameter in turn were tested using ANOVA by regarding the various maneuvers as repeated measures. The data were combined in three ways. First, all AFCS engaged maneuvers which recorded that parameter were analyzed. Second, the AFCS disengaged maneuvers were treated similarly, and finally, both sets of maneuvers were combined. The analysis enabled a better assessment of the difference between the displays for overall control of a particular parameter. A greater statistical power to examine the effect of the display and secondary task was thus possible, although it would be inappropriate to use this grouping of data to quantitatively assess 3-way interactions. The 3-way graphs supporting this analysis are therefore descriptive only. A summary of the ANOVA results is at table 15.

Table 15.
Significance (p) values for instrument flight parameters.

Parameter	Maneuvers included	AFCS On / Off	Display effect	Display vs. secondary task	*Associated Figures*
Airspeed	**all**	On	0.0000	0.0550	*37*
Airspeed	-ditto-	Off	0.0000	0.0581	*38*
Airspeed	-ditto-	On + Off	0.0000	0.0237	*39*
Roll angle	**all**	On	0.0000	0.0207	*42*
Roll angle	-ditto-	Off	0.0000	0.0381	*43*
Roll angle	-ditto-	On + Off	0.0000	0.0028	*44*
Altitude	**SL + turns**	On	0.0000	0.0001	*49*
Altitude	-ditto-	Off	0.0000	0.4601	*50*
Altitude	-ditto-	On + Off	0.0000	0.0004	*51*
Heading	**SL + climbs and descents**	On	0.0000	0.0329	*54*
Heading	-ditto-	Off	0.0000	0.3752	*55*
Heading	-ditto-	On + Off	0.0000	0.0373	*56*
Turn rate	**all turns**	On	0.0000	0.0214	*59*
Turn rate	-ditto-	Off	0.0000	0.0431	*60*
Turn rate	-ditto-	On + Off	0.0000	0.0097	*61*
Vertical Speed	**climbs**	On	0.0000	0.8689	*64*
Vertical Speed	**descents**	Off	0.0000	0.6217	*65*
Vertical Speed	**climbs + descents**	On + Off	0.0000	0.7059	66

*SL = Straight and Level. Shaded cells are non-significant

Airspeed

Airspeed RMS error was one of only two parameters that were recorded for all maneuvers. The graphical results of ANOVA are presented in figures 37 through 41. Although the 2-way interactions between the display type and secondary task just failed to reach significance for both the AFCS ON and AFCS OFF maneuvers, the combination of the two conditions produced a significant difference. There were also highly significant main effects in favor of the novel

display under each condition and the combination. Figures 40 and 41 illustrate the excellent control of airspeed when using the novel display which is relatively unaffected by the presence of the secondary task. This is in contrast to the performance using standard instruments where a fatiguing effect is apparent as the instrument flying profile progressed.

Roll angle

Roll angle RMS error was the second of the two parameters that were recorded for all maneuvers. The graphical results of ANOVA are displayed at figures 42 through 48. For clarity, the graphs of roll angle RMS error vs. maneuver (figures 45 - 48) have been divided into non-turning and turning maneuvers. There were significant 2-way interactions between the display type and secondary task for both the AFCS ON and AFCS OFF maneuvers, and for the combination of the two conditions. There were highly significant main effects in favor of the novel display under each condition and the combination. The graphs of control of roll angle by maneuver (figures 42 through 48) illustrate the excellent control of this parameter when using the novel display which is relatively unaffected by the presence of the secondary task. This is in contrast to the performance using standard instruments where a fatiguing effect is apparent as the instrument flying profile progressed.

Altitude

Altitude RMS error was measured for all maneuvers except climbs and descents (six maneuvers with AFCS engaged, and three maneuvers with AFCS disengaged). The graphical results of ANOVA are displayed at figures 49 through 53. There were significant 2-way interactions between the display type and secondary task for the AFCS ON maneuvers, and for the combination of the two conditions. There were highly significant main effects in favor of the novel display under each condition and the combination. Figures 52 and 53 illustrate the control of altitude by maneuver. Once again, the excellent control of this parameter when using the novel display is demonstrated. This is in contrast to the performance using standard instruments where a fatiguing effect is apparent as the instrument flying profile progressed.

Heading

Heading RMS error was measured for all maneuvers except turns (five maneuvers with AFCS engaged, and four maneuvers with AFCS disengaged). The graphical results of ANOVA are displayed at figures 54 through 58. There were significant 2-way interactions between the display type and secondary task for the AFCS ON maneuvers, and for the combination of the two conditions. There were highly significant main effects in favor of the novel display under each condition and the combination. Figures 57 and 58 illustrate the control of altitude by maneuver. The excellent control of this parameter when using the novel display is demonstrated. This is in contrast to the performance using standard instruments. Both displays appeared to produce a fatiguing effect as the instrument flying profile progressed, but this was more marked for the standard instruments.

Turn rate

Turn rate RMS error was measured for all turning maneuvers (three maneuvers with AFCS engaged, and three maneuvers with AFCS disengaged). The graphical results of ANOVA are displayed at figures 59 through 63. There were significant 2-way interactions between the display type and secondary task for both the AFCS ON and AFCS OFF maneuvers, and for the combination of the two conditions. There were also highly significant main effects in favor of the novel display under each condition and the combination. Figures 62 and 63 illustrate the control of turn rate by maneuver. Once again, the excellent control of this parameter when using the novel display was demonstrated. There was no evidence of fatigue in this case.

Rate of climb

Rate of climb RMS error was measured for all climbing and descending maneuvers (two maneuvers with AFCS engaged, and four maneuvers with AFCS disengaged). The graphical results of ANOVA are displayed at figures 64 through 68. There were no significant 2-way interactions between the display type and secondary task for any combination of data, but there were highly significant main effects in favor of the novel display under each condition and the combination. Figures 67 and 68 illustrate the control of rate of climb by maneuver. A fatiguing effect is apparent as the instrument flying profile progressed for performance using the standard instruments.

Qualitative illustration of the instrument flying profile

Figures 69 through 72 are graphs drawn from raw data of two of the subjects. They illustrate the variation in altitude and airspeed over the whole instrument flying profile. Subject 11 was a very experienced pilot with 5000 hours of flight time, whereas subject 15 was a newly qualified pilot with only 150 hours flight time. The profiles of these subjects have been chosen to qualitatively illustrate the extremes of experience. It can be readily seen that both subjects' performance improved when using the novel display. The difference in performance is more marked in the novice pilot.

Recovery from unusual attitudes

Recovery times

Analysis of variance was performed on the various measures of recovery from the UAs by regarding each as a repeated measure. The results are presented in table 16 and figures 73 through 79. F and p values are shown in the comprehensive series of figures and therefore will not be repeated in the text.

Table 16.

Significance (p) values for recovery from unusual attitudes.

Parameter	Display effect	Display vs. secondary task	Display vs. secondary task vs. iteration	*Associated Figures*
time to wings level	0.0001	0.0235	0.0085	*73*
time to pitch level	0.3681	0.6137	0.3313	*74*
time to airspeed	0.0001	0.5682	0.8811	*75*
time to heading	0.1083	0.0120	0.0418	*76*
time to altitude	0.0560	0.6480	0.2825	*77*
achievement of all 3 parameters	0.0432	0.3981	0.5626	*78*
maintenance of all 3 parameters for 30 seconds	0.0002	0.0114	0.0109	*79*

shaded cells are non-significant

Time to wings level

There was a significant 3-way interaction between display, secondary task and iteration. Analysis of simple effects showed this was due to better performance using the novel display compared to the standard instruments during UAs 1, 5 and 6 when the secondary task was absent for UA 1 and present for UA 5 and 6. There was also a significant 2-way interaction between the display type and secondary task in favor of the novel display, and a highly significant main effect for display for this parameter. The time to recover to wings level using the standard instruments improved when the secondary task was present. This is further discussed later in the report.

Time to pitch level appropriate to airspeed

There were no significant interactions or main effects for this parameter.

Time to recover to desired airspeed

Although there were no 3-way or 2-way interactions in the analysis of this parameter, there was a highly significant main effect in favor of the novel display. This was due to an improved performance in all the UAs in which airspeed was substantially changed (UAs 2 through 6) with the secondary task both present and absent.

Time to recover to desired heading

There was a significant 3-way interaction between display, secondary task and iteration. Analysis of simple effects showed this was due to better performance using the novel display compared to the standard instruments during UAs 4, 5 and 6 when the secondary task was absent. There was also a significant 2-way interaction between the display type and secondary task, but no significant main effect for display for this parameter. The time to recover to desired heading using the novel display improved when the secondary task was present. This is further discussed later in the report.

Time to recover to desired altitude

There were no significant interactions or main effects for this parameter.

Achievement of all three parameters

There were no significant 3-way or 2-way interactions for this parameter, but there was a significant main effect in favor of the novel display.

Maintenance of all three parameters for 30 seconds

There was a significant 3-way interaction between display, secondary task and iteration. Analysis of simple effects showed this was due to better performance using the novel display during UAs 2, 4 and 6 when the secondary task was present. There was also a significant 2-way interaction between the display type and secondary task in favor of the novel display, and a highly significant main effect for display for this parameter. The time to maintain all three parameters for 30 seconds using the novel display improved when the secondary task was present. This is further discussed later in the report.

Qualitative illustration of the unusual attitudes

Figures 80 through 91 are graphs of mean, maximum and minimum data points for the six unusual attitudes compiled from all subjects' raw data.

Initial cyclic stick movements

In order to assess the occurrence of appropriate control upon initial recovery from the unusual attitudes, the direction of initial cyclic stick movement (over the first 5 seconds) was recorded. For each UA, the ideal initial direction of cyclic movement to restore the aircraft attitude to wings level and then pitch level was calculated. A score was then awarded according to the actual direction of cyclic movement that was recorded. For example, for recovery from UA number 4, a left roll with a pitch nose down, the initial cyclic movement should be to the right followed by a rearwards movement as shown in figure 92 below. A maximum score of 4 was awarded if this was the case. Initial movements in other directions were awarded the number of points illustrated in the quadrant, e.g., an initial left movement of the cyclic would score 0, and a forward right movement would score 2.5. The scores were then subjected to ANOVA.

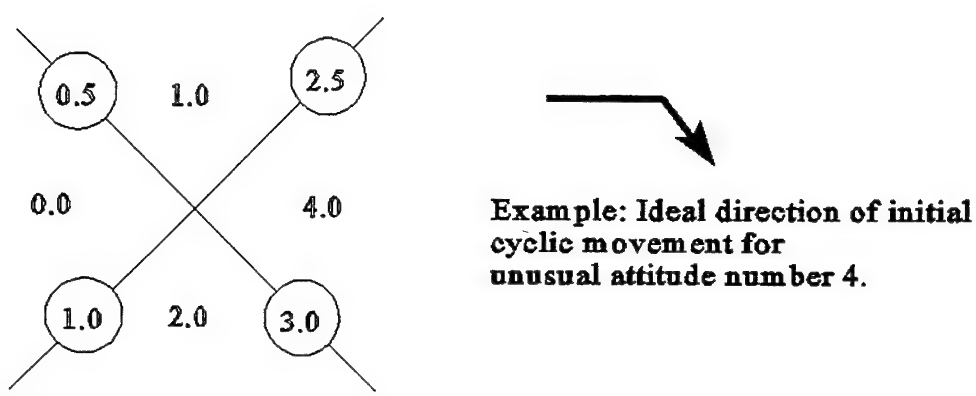


Figure 92. Example of calculation of cyclic movement score.

The results show that there was a significant main effect for display in favor of the novel display (figures 93 and 94). However, although the cyclic stick movement scores were higher for the novel display especially when the secondary task was present, the interaction between display and secondary task failed to reach a significant level. This analysis augmented the direct observation of the subject's response when undertaking the task.

Analysis of secondary task scores

The total correct and incorrect responses to the tones presented during the secondary task during both the instrument flight profile and during recovery from unusual attitudes were analyzed using ANOVA. The results are displayed at table 17 and figures 95 through 109 as individual maneuvers, and table 18 and figures 110 through 112 by maneuver type. It is clear, particularly from the latter table and the associated figures, that the novel display allowed better division of attention to a secondary task during both instrument flight and recovery from unusual attitudes. Treating the maneuvers as repeated measures (figures 113 through 115), the overall main effect for display for the instrument flight profile was significant in favor of the novel display for total, correct and incorrect responses ($p<0.0001$, $p<0.0001$, and $p<0.0002$ respectively). Similarly, the main effect for unusual attitude recovery was also significant for total, correct and incorrect responses ($p<0.0433$, $p<0.0019$, and $p<0.0054$, respectively).

Table 17.
Significance (p) values for secondary task by individual maneuver compared across the two displays.

Maneuver	Total responses	Correct responses	Incorrect responses	*Associated Figures*
Straight and level 1	0.1013	0.0000	0.0000	*95 100 105*
Left standard rate turn 1	0.0384	0.0611	0.3232	*95 100 105*
Straight and level 2	0.0235	0.0053	0.0015	*95 100 105*
Climb 1	0.8094	0.0609	0.0245	*95 100 105*
Right standard rate turn 1	0.0731	0.0125	0.1772	*96 101 106*
Straight and level 3	0.0007	0.0000	0.4947	*96 101 106*
Right standard rate turn 2	0.0186	0.0221	0.4716	*96 101 106*
Climb 2	0.0257	0.0414	0.0853	*96 101 106*
Descent 1	0.0008	0.0098	0.7394	*97 102 107*
Left descending turn	0.0581	0.0020	0.0271	*97 102 107*
Descent 2	0.0000	0.0000	0.0565	*97 102 107*
Left standard rate turn 2	0.0012	0.0054	0.2281	*97 102 107*
Straight and level 4	0.0042	0.0040	0.0737	*98 103 108*
Right standard rate turn 3	0.1999	0.3257	0.0013	*98 103 108*
Descent 3	0.0692	0.0028	0.0014	*98 103 108*
Unusual attitude number 1	0.2006	0.0545	1.000	*99 104 109*
Unusual attitude number 2	0.0008	0.2230	0.0002	*99 104 109*
Unusual attitude number 3	0.8655	0.2808	0.0002	*99 104 109*
Unusual attitude number 4	0.3835	0.0139	0.0349	*99 104 109*
Unusual attitude number 5	0.0000	0.0010	0.7732	*99 104 109*
Unusual attitude number 6	0.0036	0.2849	0.2523	*99 104 109*

shaded cells are non-significant

Table 18.
Significance (p) values for secondary task by maneuver type.

Maneuver	Total responses	Correct responses	Incorrect responses	*Associated Figures*
Straight and level	0.0000	0.0000	0.0005	*110 111 112*
Level turns	0.0000	0.0005	0.0028	*110 111 112*
Climbs	0.0869	0.0310	0.0244	*110 111 112*
Descents	0.0009	0.0005	0.2149	*110 111 112*
Unusual attitudes	0.0433	0.0019	0.0054	*110 111 112*

shaded cells are non-significant

Subjective questionnaire results

The rating scores from each question of the subjective questionnaire were analyzed using paired t-tests for dependent samples. The results are displayed in figures 116 through 119. All results were significant in favor of the novel display, with the exception of presentation of angle of bank and pitch information.

Subjects' comments

Additional comments have been collated and are presented below. The number of subjects providing the comment is in parentheses and a response to bad points is also made.

Good points:

a. More accurate control is possible (7).

b. Eases instrument scan - all pertinent data within focal vision with minimal head movement (6).

c. Very good information on airspeed, altitude and vertical speed (6).

d. Very easy to learn to use the display (5).

e. The set parameters are a great idea (5).

f. Eases some of the "division of attention" required with conventional instruments and thus reduces workload (4).

g. Eases workload required to recover from unusual attitudes - removes uncertainty during recoveries (4).

h. Use of color enhances information assimilation from periphery of display (4).

i. Eye friendly - easy to read (4).

j. Excellent prompt when to roll out of turn (3).

k. Encourages less over-control (1).

l. Shows actual flight information rather than just the trend (1).

m. Does a good job of telling corrections required (1).

Bad points:

a. Lack of horizon - very little pitch and angle of bank information. Found it more difficult to picture the situation of the aircraft in an unusual attitude (but it was easier to recover)(5).
Response: This is discussed in detail later in the report.

b. Initially difficult to use the novel display (i.e., wanted to fly the grid of squares to the triangle rather than fly the triangle into the center box). With practice, I grew accustomed to flying the icon and it became much easier (3).
Response: This is discussed in detail later in the report.

c. Tendency to stare at center of screen (3).
Response: All subjects were naturally used to scanning standard instruments and so a criticism of this nature was expected. It is counteracted by the comment at subparagraph (b) in the good points.

d. Torque (power) values should also be on display (2).
Response: The torque meters on the simulator instrument panel were not included in the display, as when it was mounted in the simulator, the flat panel did not cover the indicators. Therefore, to avoid confusion in having the same information presented in two different places during this assessment, torque values were excluded from the display. Future variations of the display could easily accommodate torque values if required.

e. Color of triangle and altitude ribbon strip should be the same when above desired altitude (2).
Response: The altimeter ribbon strip appeared blue when altitude was more than 20 feet above the set altitude. The triangle turned amber above this value. Because the triangle was expected to always be in a pilot's central focal vision, blue was not selected for this indication because of the unreliability of discrimination from the "on target" color of green. The color could readily be changed if so desired.

f. Larger numerals for speed, heading and altitude (1).
Response: Software programming constraints necessitated the size of display fonts for this assessment. Future versions could incorporate larger fonts.

Other comments:

a. I believe the novel display should be integrated into future designs and modifications (4).
Response: This is hopefully the intention.

b. I think the novel display should be integrated into electronic flight information systems (EFIS) for specific uses such as flying instrument approaches since it results in such precise flight. Maybe it could be a mode of EFIS that could be selected as an option to the standard instrument display (1).
Response: Time constraints in the execution of this project prevented an instrument approach mode from being developed. Nevertheless, such further development is possible.

c. Is it possible to prompt leveling from a climb in a similar fashion to prompting the roll-out from a turn?
Response: Again, this enhancement to climbing maneuvers was considered, but time constraints prevented its development at this stage. It would be possible.

Simulator sickness questionnaires

There were no nausea, visuomotor, disorientation or total scores of significant magnitude to suggest that simulator sickness was a problem with either display. Both pre- and postflight responses, and the postflight responses for the two types of display were analyzed using paired t-tests for dependent samples. There was no significant difference in any of the analyses.

Discussion

Instrument flying

This study set out to study two hypotheses. The first, that during instrument flying, the novel display permits more accurate maintenance of flight parameters than the standard instrument display, has been overwhelmingly proven. Although not every parameter measured in each maneuver was statistically better maintained using the novel display, the majority were, and so an overall benefit in this respect from the novel display can be justified. In their original report on this novel display, Durnford and DeRoche (1995) were only able to conclude that the novel display was "no worse" as a flying aid than standard instruments. This study has demonstrated otherwise. The benefits of accurate flight were greatest in the maintenance of airspeed and roll angle, the two measurable parameters that were directly enhanced by the principle of the novel display - integration of the orientational functions of pitch and roll. Control of heading and turn rate were almost as well controlled, but as these are derivatives of the primary enhancement to control, it is not surprising that maintenance of these factors was not as good as airspeed and roll angle.

Although there was a statistically significant improvement in the accuracy of rate of climb and descent when using the novel display, this parameter was the least improved. This was because control of vertical speed and thus altitude was essentially the same as that used when flying with standard instruments; i.e., increasing or reducing the power (collective) setting to achieve the desired value and monitoring the effect. Nevertheless, primarily because of the inclusion in the display of a more easily assimilated presentation of altitude and vertical speed (color-coded ribbon strips), control was better.

Analysis of airspeed, roll angle, and altitude across the maneuvers all showed some element of a fatiguing effect as the instrument profile progressed when using the standard instruments, but much less so, if at all for the novel display. Analysis of heading error provided evidence of fatigue for both displays, but not as marked for the novel display compared to the standard instruments. Instrument flying is a demanding task and so any improvement to alleviate fatigue must be welcome.

The vast majority of RMS error scores during instrument flight showed little degradation between the conditions of secondary task absent and present when using the novel display, whereas there was a marked difference in many instances when using the standard instruments. There was not a significant 2-way interaction between display and secondary task for all maneuvers. However, analysis of the secondary task score for each maneuver both individually and when grouped into type showed a significant improvement in at least one of the scoring parameters (total, correct and incorrect responses) in all cases. This result, together with the overall improved accuracy of flight, supports the subjective evidence that the workload associated with the novel display is less than that required to fly with the standard instruments.

Unusual attitudes

The second hypothesis that was examined in this study was "during recovery from unusual attitudes, the novel display permits faster and more accurate reestablishment of flight parameters than the standard display." It was with this aim in mind that the novel display was originally designed. Durnford and DeRoche (1995) presented subjects with the end point of an unusual attitude in a static simulator. The drawbacks of that approach are discussed fully in their report. Because this study was conducted in a dynamic flight simulator and not an actual aircraft, there were also limitations on how well recovery could be assessed. Two aspects are readily apparent. First, although the simulator was programmed to "fly itself" into various unusual attitudes, the dynamic input to a subject pilot was not the same as would be experienced in the actual flight environment. Simulators employ a "washout" of initial acceleration forces especially about the roll axis to simulate that motion. The semicircular canals and otolith organs of the vestibular apparatus are thus not stimulated to the same degree as actual flight. The subject pilot is therefore not properly "disoriented" during these maneuvers, although his flight instruments will accurately display the actual and trend of motion away from the original parameters. Second, the subject pilot is fully aware that he is taking part in an experiment in a simulator that will allow him to make large control movements or even control errors without endangering himself or the aircraft. There were several other projects at this institution being conducted in the Laboratory UH-60 aircraft at the time of this assessment and mounting the display in the actual aircraft would have been difficult and prevented concurrent research activity. As a natural "next step" to proving this display, it was therefore deemed appropriate to conduct this experiment in the simulator. The outcome of these limitations meant that a true representation of the display's performance in this aspect would probably not have been possible. Nevertheless, several advantages to the novel display became apparent.

All aircrew are trained that the initial action upon recovery from an unusual or unwanted attitude is to level the wings of the aircraft. The results of this experiment show that the main effect of recovery times to wings level was significantly faster when using the novel display. This conclusion, together with the significant finding that recovery from unusual attitudes in all bar UA number 1 was associated with significantly less initial cyclic control errors (effectively control reversal) when using the novel display, is consistent with the novel display's ability to enhance recovery from spatial disorientation.

The second action upon recovery from an unusual attitude is to level the pitch of the aircraft. Although the trend of the analysis of time to achieve this was in favor of the novel display, the effect did not reach a statistically significant level. Pitch representation in the novel display is discussed below, and because of relative unfamiliarity with the device, it was probably this aspect that prevented a significant result. It must be remembered, however, that subjects rated the novel display as imposing significantly less workload to recover from unusual attitudes than the standard instruments.

The reattainment of original flight parameters in terms of airspeed, heading and altitude is the essential end result of recovery from an unusual attitude. This study revealed a significant main effect for recovery time to airspeed in favor of the novel display. A helicopter's airspeed is directly related to its pitch angle, and thus, the former contributes to overall correct orientation; therefore, it is arguably more important to achieve this original parameter than the two others. Recovery to airspeed (+/- 10 knots) was consistently faster for all unusual attitudes bar number 1 (no airspeed changes were imposed on this UA), and although the interaction between display and secondary task was not significant, there was no degradation of performance when the secondary task was present.

Neither the time to recover to heading nor the time to recover to altitude was significantly different between the two displays. There are two possible reasons that affected this part of the assessment. First, when correcting to a heading, the novel display was designed to apply a roll angle of no more than 15 degrees. This was reduced progressively as soon as the heading was within 20 degrees of the desired value. There was, of course, no similar restriction placed on flight using the standard instruments, and subjects frequently applied a roll angle to correct heading of 30 degrees or more. Heading recoveries using the novel display were thus artificially "slowed." Examination of the qualitative graphs of recovery from unusual attitudes for which heading is plotted (figures 81, 87, 89 and 91) does, however, show that there was less variation during recoveries when using the novel display. Second, correction of altitude necessitated a change in torque (power) setting. This aspect of the novel display is secondary to its primary function of assisting attitude control. It was noted that particularly among the less experienced pilots, altitude recovery was slow especially when the secondary task was present. This consecutive rather than concurrent activity is a common feature noted in inexperienced aircrew by instrument instructor pilots. It is therefore not surprising that there was no significant difference between the two displays in these measurements.

There was a significant main effect in favor of the novel display in the time taken to achieve all three parameters of airspeed, heading and altitude, and furthermore, a similar benefit in the maintenance of these parameters for 30 seconds. The latter measurement was introduced to assess how well subjects could retain controlled flight following a "disorienting" episode. The timer for the maintenance of original values of airspeed, heading and altitude was returned to zero if a subject strayed outside any parameter. Both observation of subjects and analysis of the results revealed that the benefit of the novel display was due primarily to airspeed and heading being maintained. This was probably because of the more readily monitored presentation of these data, i.e., keeping the triangle in the center box. In particular, six subjects were noted to have overshot various parameters when using the standard instruments and delayed their response to this error. There were no instances of this during recoveries using the novel display.

It can be seen in the data from unusual attitude recovery that performance tended to improve when the secondary task was present. This was a more common occurrence when using the standard instruments than when flying with the novel display. None of the interactions in which this occurred were significant. Nevertheless, this finding is counterintuitive. A probable

explanation is that as instructed, subjects concentrated on the primary task and "ignored" the secondary task when workload was high. The maneuver therefore became essentially the same as that without a secondary task. Scrutiny of the data suggests that the improvement was affected by the improved performance of those subjects who flew sorties with the secondary task after the sortie without a secondary task; i.e., despite precautions taken to the contrary, there was an apparent learning effect for the unusual attitude recoveries.

The effect of the secondary task on flight performance was not as marked during the recovery from unusual attitudes as it was during the instrument flight profile. It is clear, however, from the scores on the secondary task, that the novel display allowed better division of attention to a secondary task during both instrument flight and recovery from unusual attitudes. It can therefore be concluded that when using the novel display, accurate flight and satisfactory recovery from episodes of disorientation can be achieved with less cognitive workload.

Subjective comments

The subjective questionnaire provided overwhelming evidence in favor of the novel display. With the exception of presentation of angle of bank and pitch, all questions were rated significantly higher in favor of the novel display. The additional "good point" comments further support the advantage. There were two criticisms of the novel display that are worthy of detailed comment. The first was the absence of pitch and roll information. The experienced pilots particularly missed the representation of aircraft attitude relative to the earth with which they were familiar in the standard instrument display. This was considered to be solely a function of their previous extensive training in that they had learned to interpret the traditional display of pitch and roll from the attitude indicator. It is a fundamental principle of the novel display that it was designed to reduce the cognitive workload of interpretation of standard flight instrument symbology. There have been many reports in literature where misinterpretation of symbology during a disorienting episode has contributed to, or directly led to loss of aircraft control and consequent mishap. It can be argued that in this type of circumstance, when instrument scan has broken down and so cognition of correct orientation has been lost, there is a requirement to simplify the information presented to the pilot to recover the situation to controlled flight. In other words, the pilot no longer requires to know his absolute attitude, but requires advice on the control movements needed to recover. By returning the triangle symbol to the central square, the novel display does exactly this. The second criticism, again made more often by experienced pilots, was the tendency during the early phase of training on the novel display, to "fly" the grid of squares over the triangle, rather than make cyclic control movements to move the triangle into the central square. This again is a function of previous learning with traditional "inside - out" attitude displays in which one moves a fixed attitude bar over the relative horizon of the attitude indicator globe. Although there was an occasional lapse to previously learned behavior, the perceived problem was generally overcome by all subjects during the test sessions.

Subject pilots liked the provision of set parameters for airspeed, heading and altitude, and the ability of the novel display to prompt them to roll out of a turn onto a new heading. The set parameters obviated the necessity to remember to which new settings they were flying. There were no requests for the simulator operator to repeat the new values when flying with the novel display, whereas it was a common occurrence with the standard instruments, especially when the secondary task was present. One frequent question asked during debriefing periods was how the set parameters could be programmed into the display should this device be incorporated into future aircraft systems. This aspect is beyond the scope of this concept assessment, but with modern technology, values of airspeed, heading and altitude could readily be input by keyboard controls, digital data transmission before the flight or from a ground station, or even by voice command.

The novel display was clearly easy to learn as supported by both questionnaire comments, and the fact that subjects performed better than with standard instruments after only 3 hours training on the device. This was true for both the novice pilot and for those who had several thousand hours of flight and instrument time.

Future development

As with Durnford and DeRoche's original work (1995), no attempt was made in this experiment to superimpose the display on a scene depicting the outside world. The display was designed with that use in mind, however, and with more general fielding of the NVG HUD, further development along this path might now be warranted. The central squares and other elements could easily be replaced or adapted in such a way that they would be less obscuring. Since this experiment has been concluded, an attempt to provide hover information on the display is being developed. The display has been reconfigured by replacing the moving triangle with a helicopter icon. Movement of the icon across the central grid now represents drift from the original "zeroed" hover position, and its rotation denotes heading error from the original heading. Actual values of heading are still displayed. The altitude strip displays radar altitude and the vertical speed indicator displays rate of change of radar altitude. The airspeed indicator has been converted to represent ground speed. It is also the intention to address the suggestions made by the subjects in the questionnaire; i.e., an instrument landing system, and to prompt leveling off from a climb or decent.

Conclusions

The results of this experiment provide further strong evidence that the concepts behind the novel display are workable, and that it indeed makes recovery from unusual attitudes and instrument flying easier than when using the standard instruments.

The display should be developed further to make it possible to superimpose it upon outside scenes. It should also be developed to be able to provide information on hovering and instrument landing, preferably in actual flight.

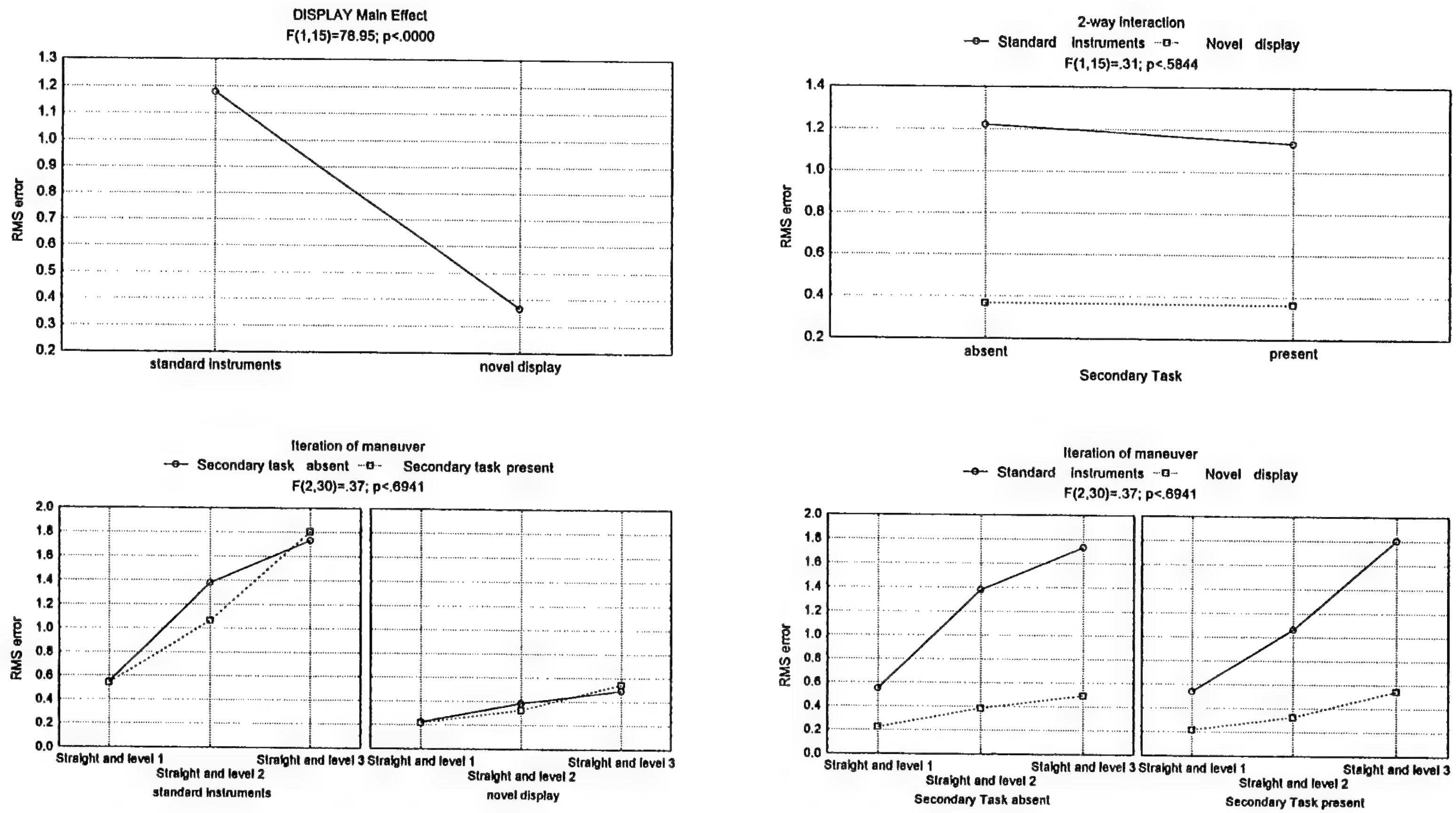


Figure 9. Maneuver = straight and level, parameter = airspeed, AFCS ON.

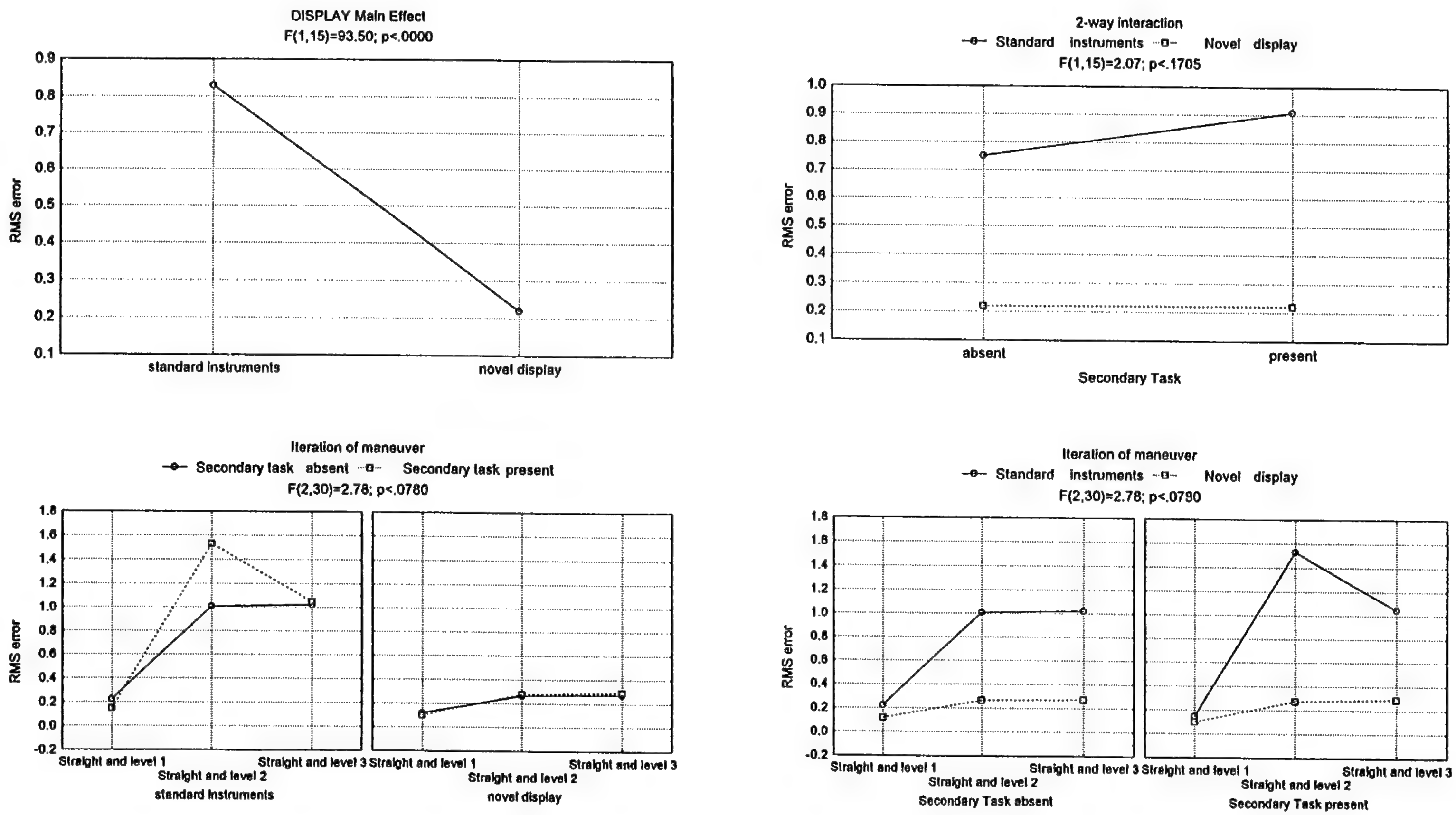


Figure 10. Maneuver = straight and level, parameter = roll angle, AFCS ON.

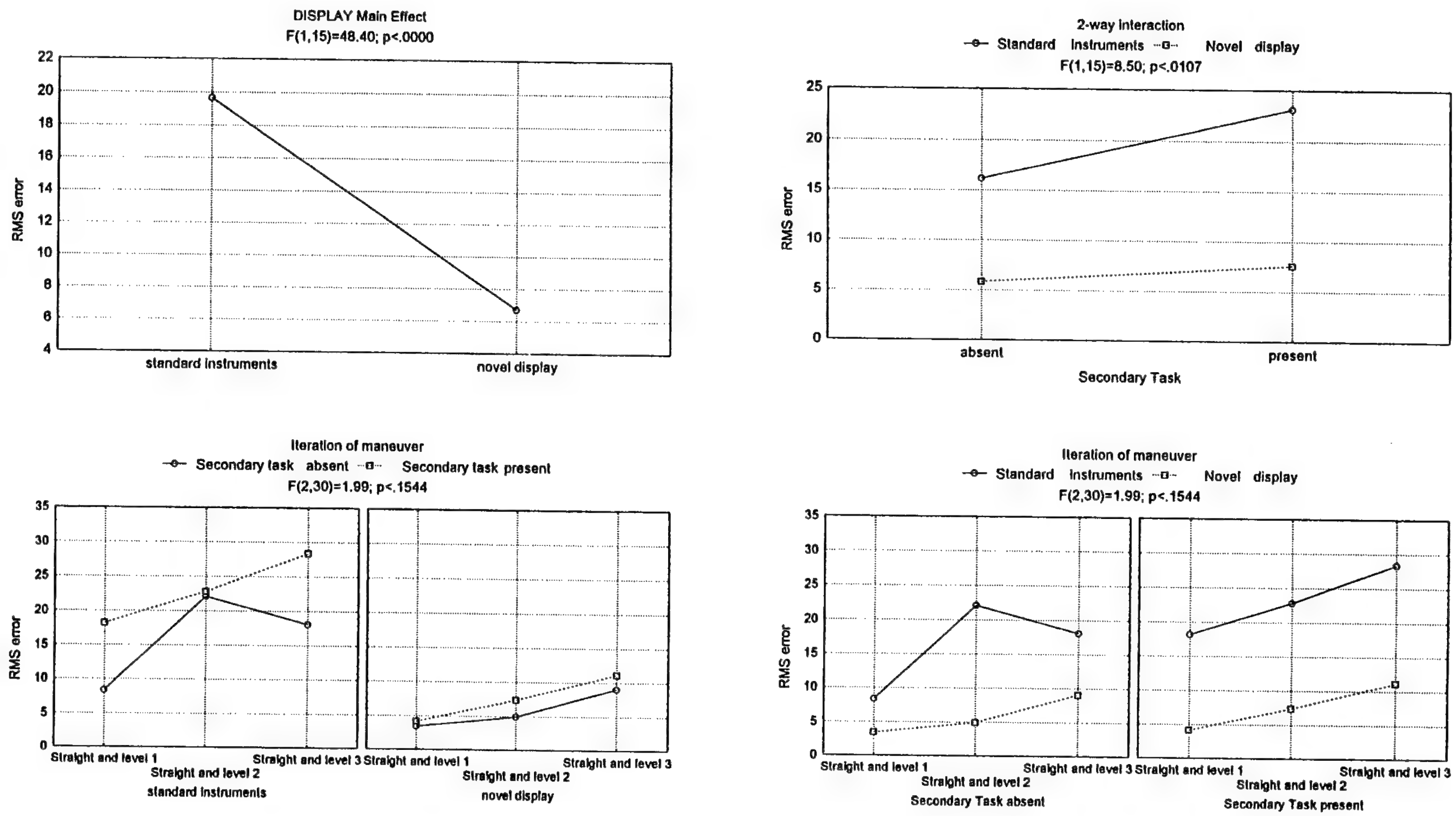


Figure 11. Maneuver = straight and level, parameter = altitude, AFCS ON.

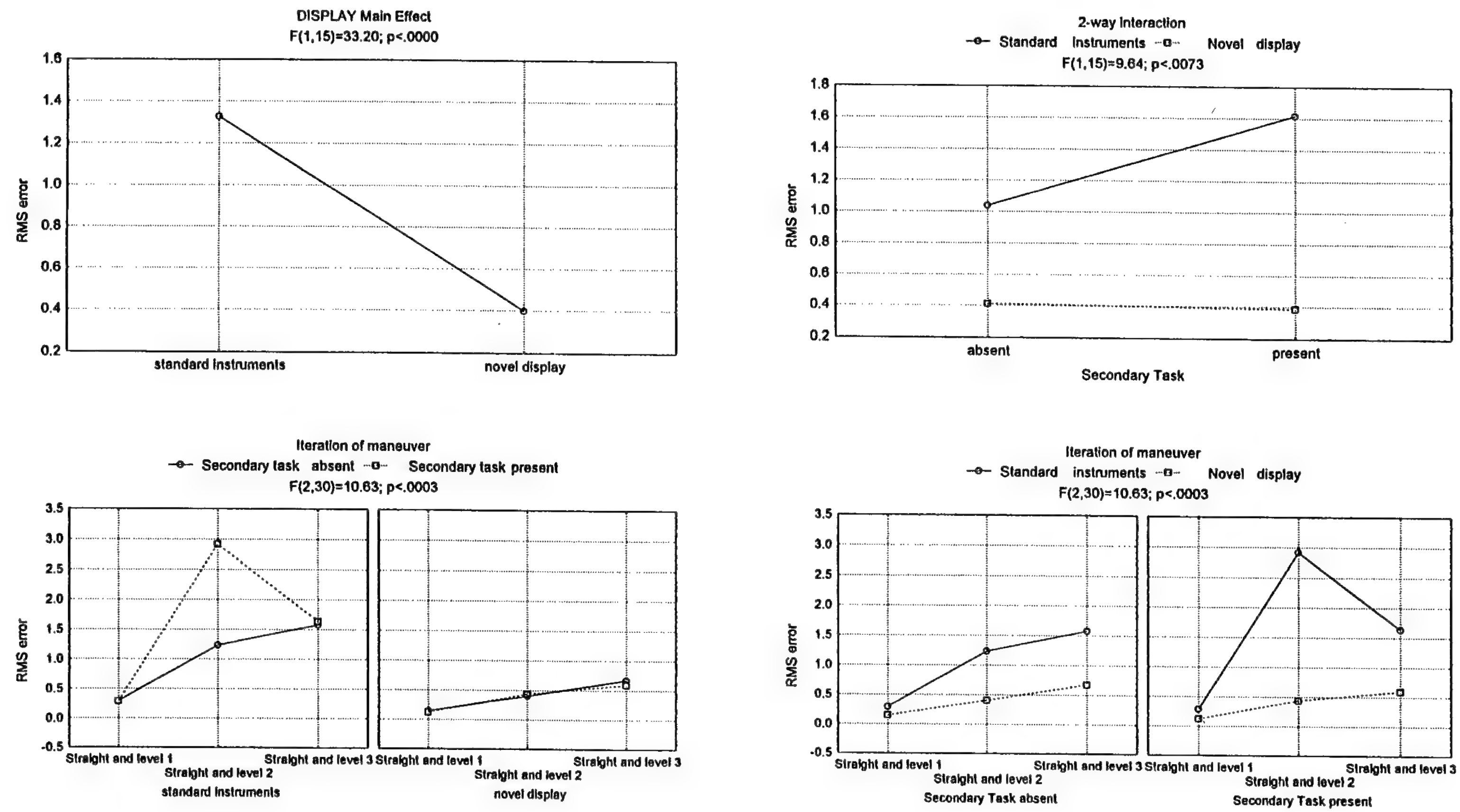


Figure 12. Maneuver = straight and level, parameter = heading, AFCS ON.

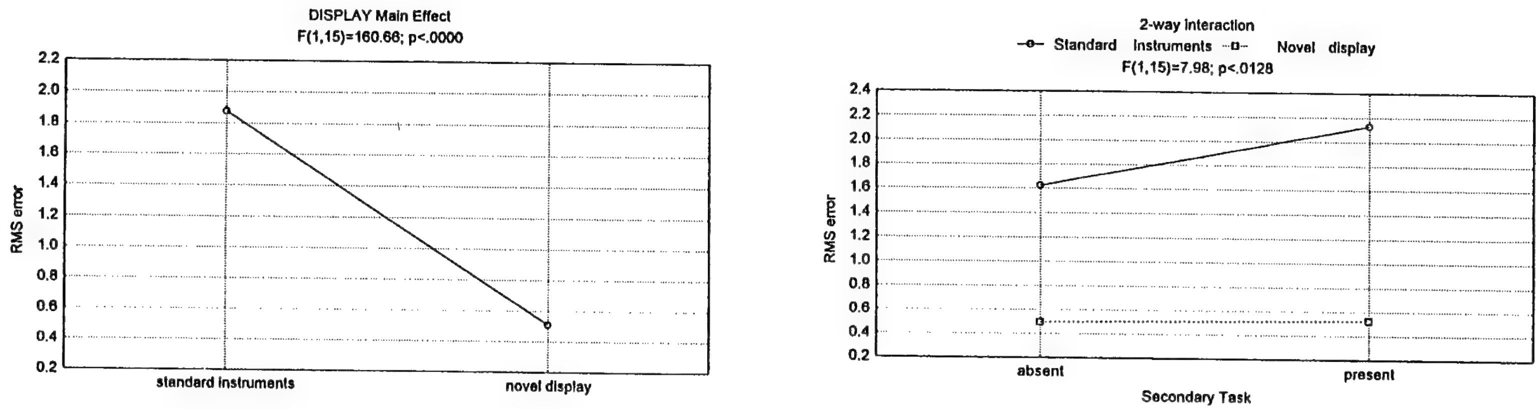
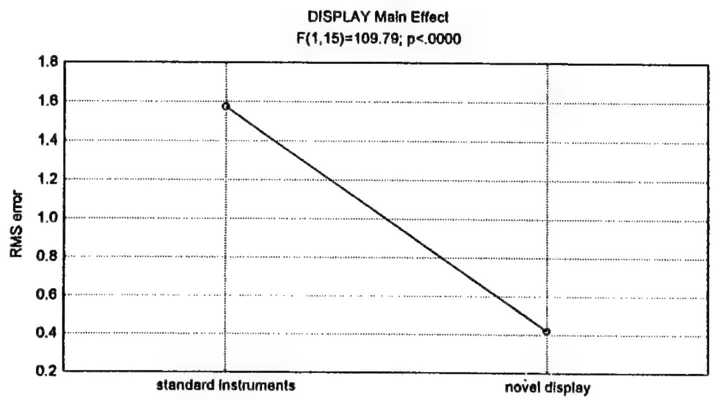


Figure 13. Maneuver = straight and level, parameter = airspeed, AFCS OFF.



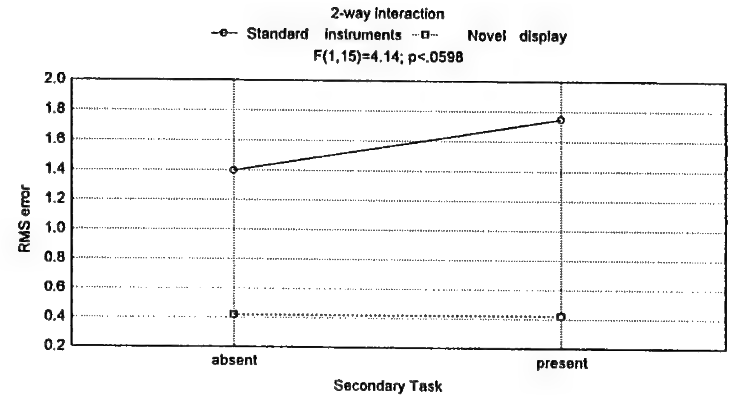


Figure 14. Maneuver = straight and level, parameter = roll angle, AFCS OFF.

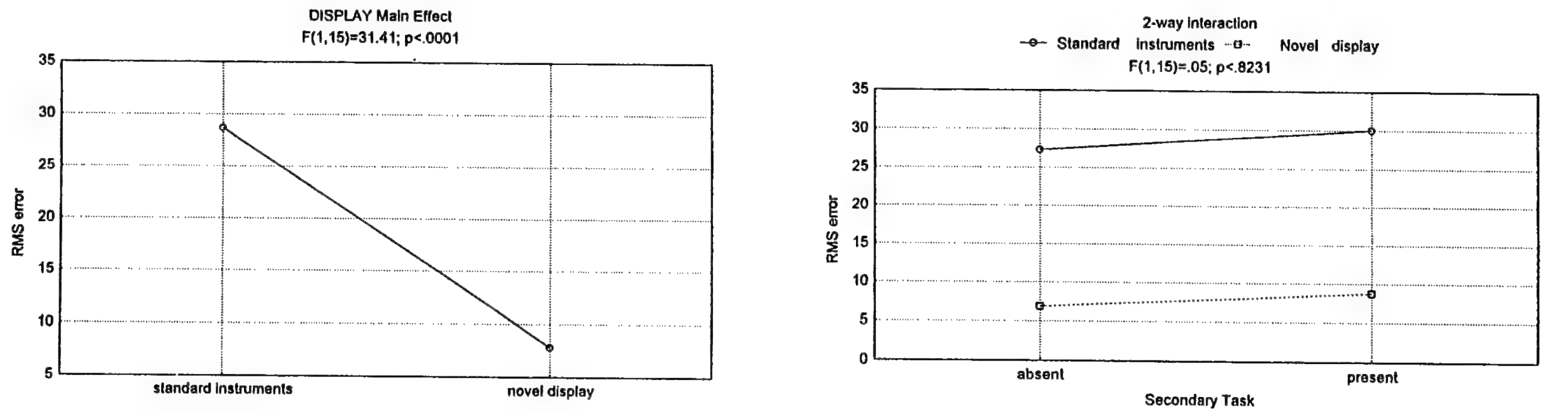


Figure 15. Maneuver = straight and level, parameter = altitude, AFCS OFF.

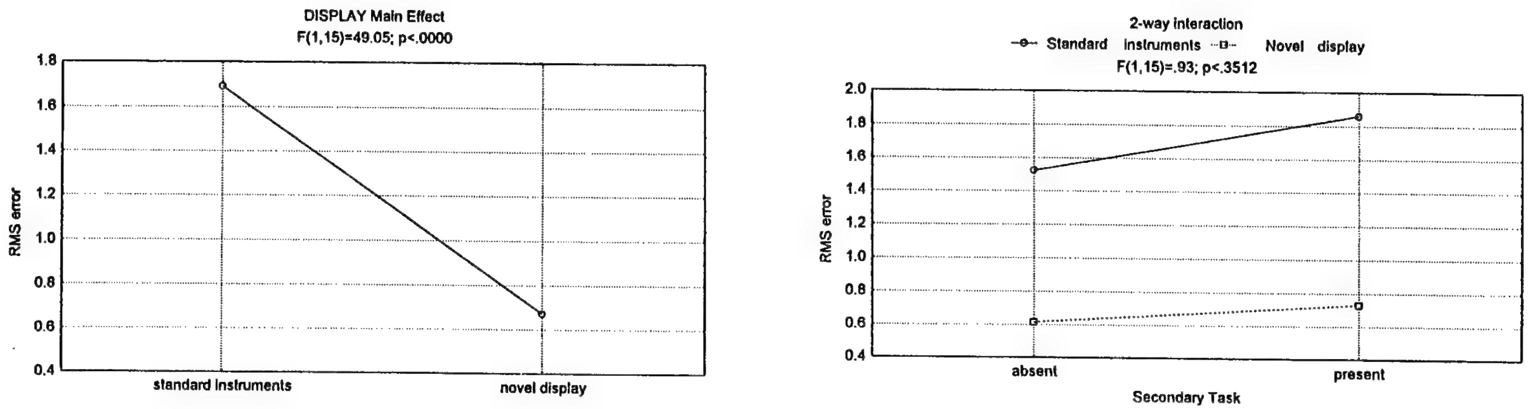


Figure 16. Maneuver = straight and level, parameter = heading, AFCS OFF.

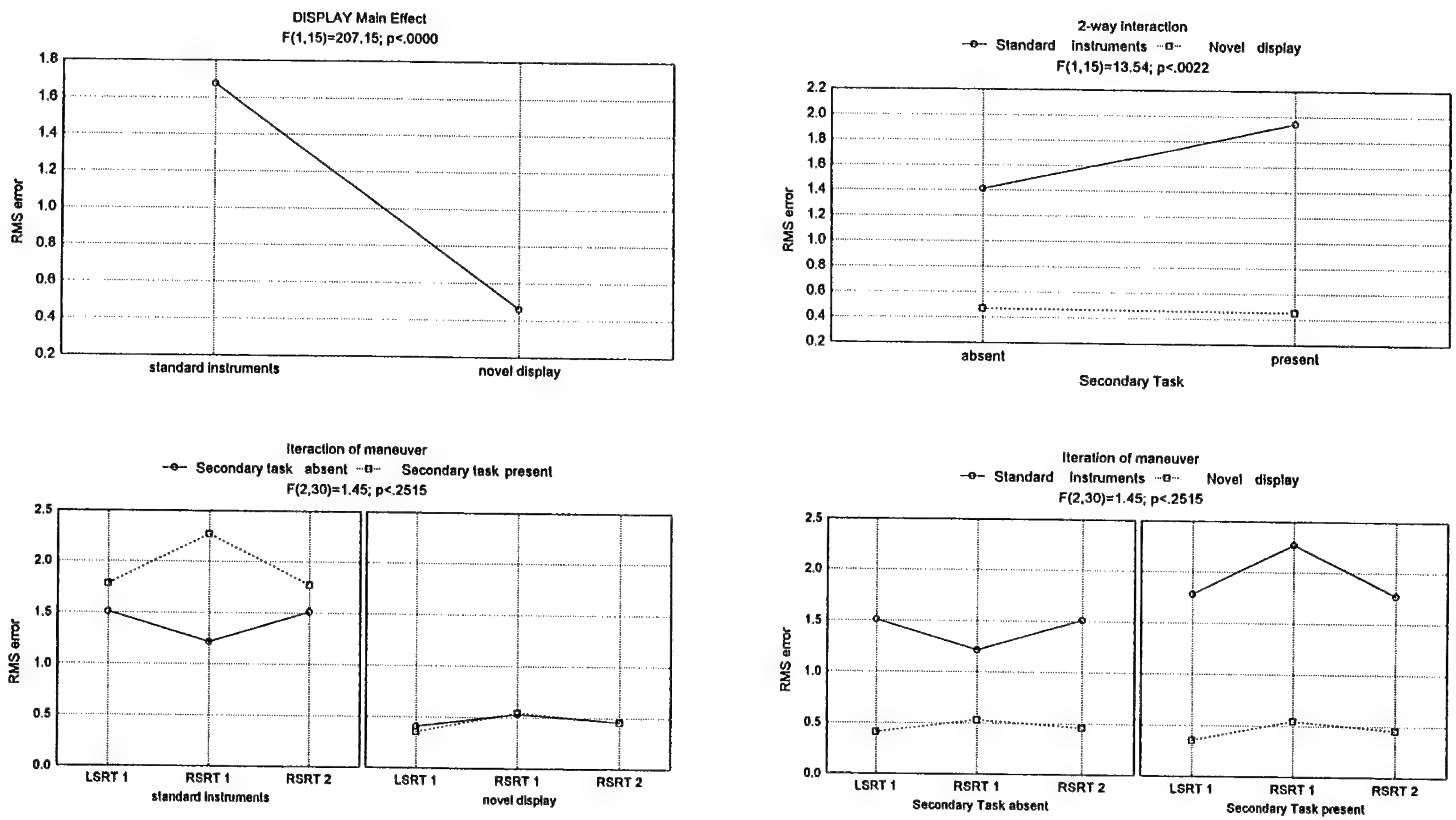


Figure 17. Maneuver = turns, parameter = airspeed, AFCS ON.

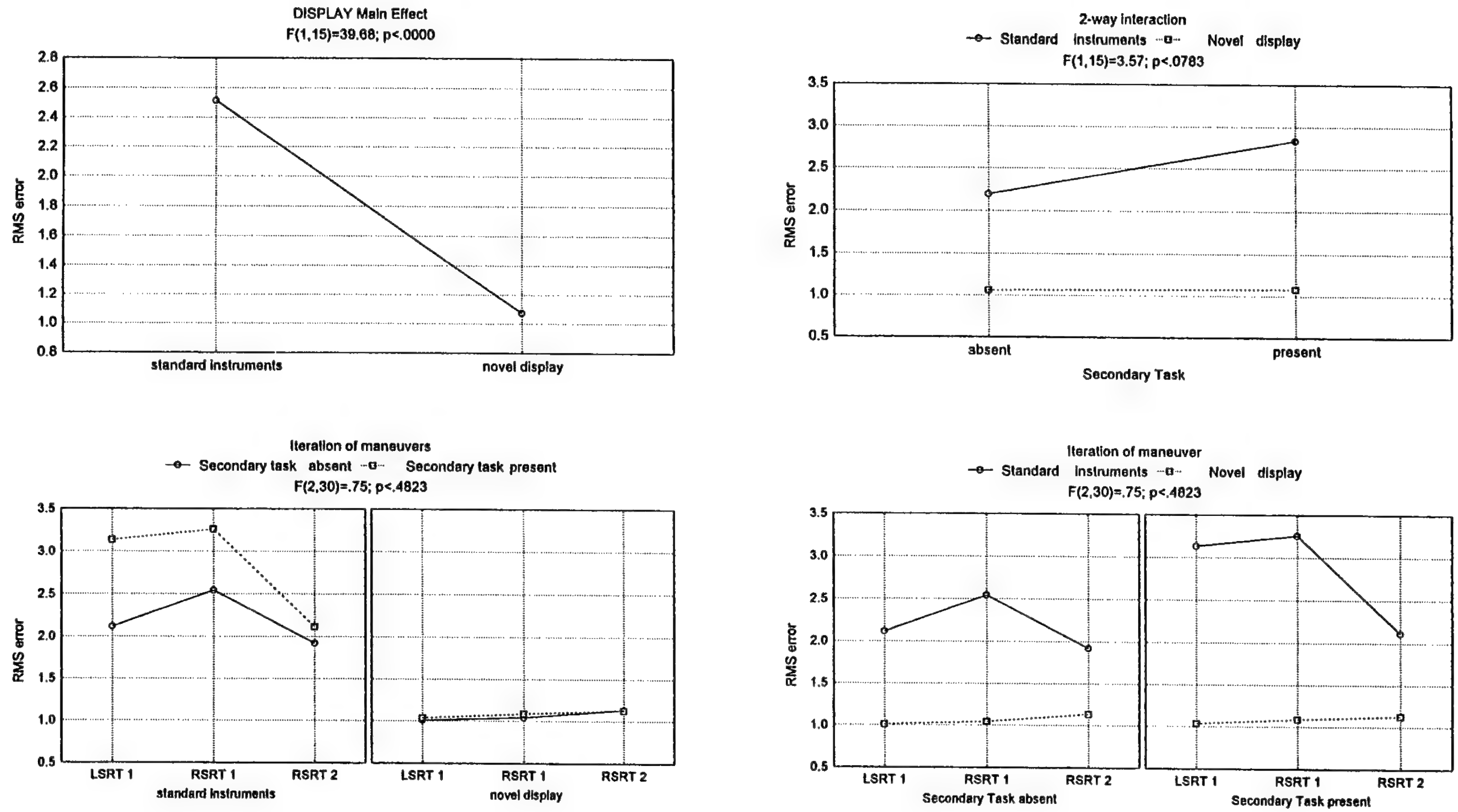


Figure 18. Maneuver = turns, parameter = roll angle, AFCS ON.

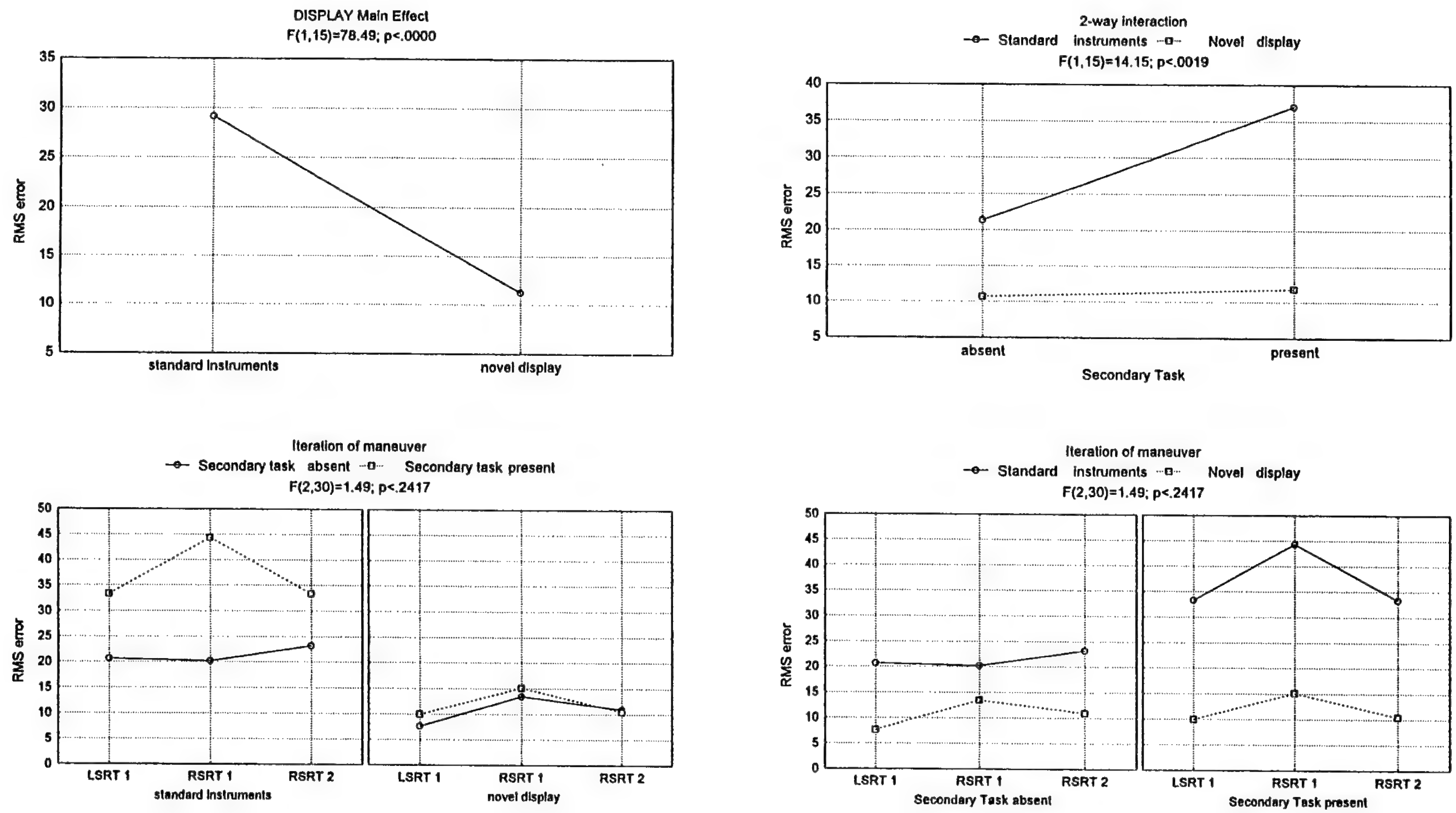


Figure 19. Maneuver = turns, parameter = altitude, AFCS ON.

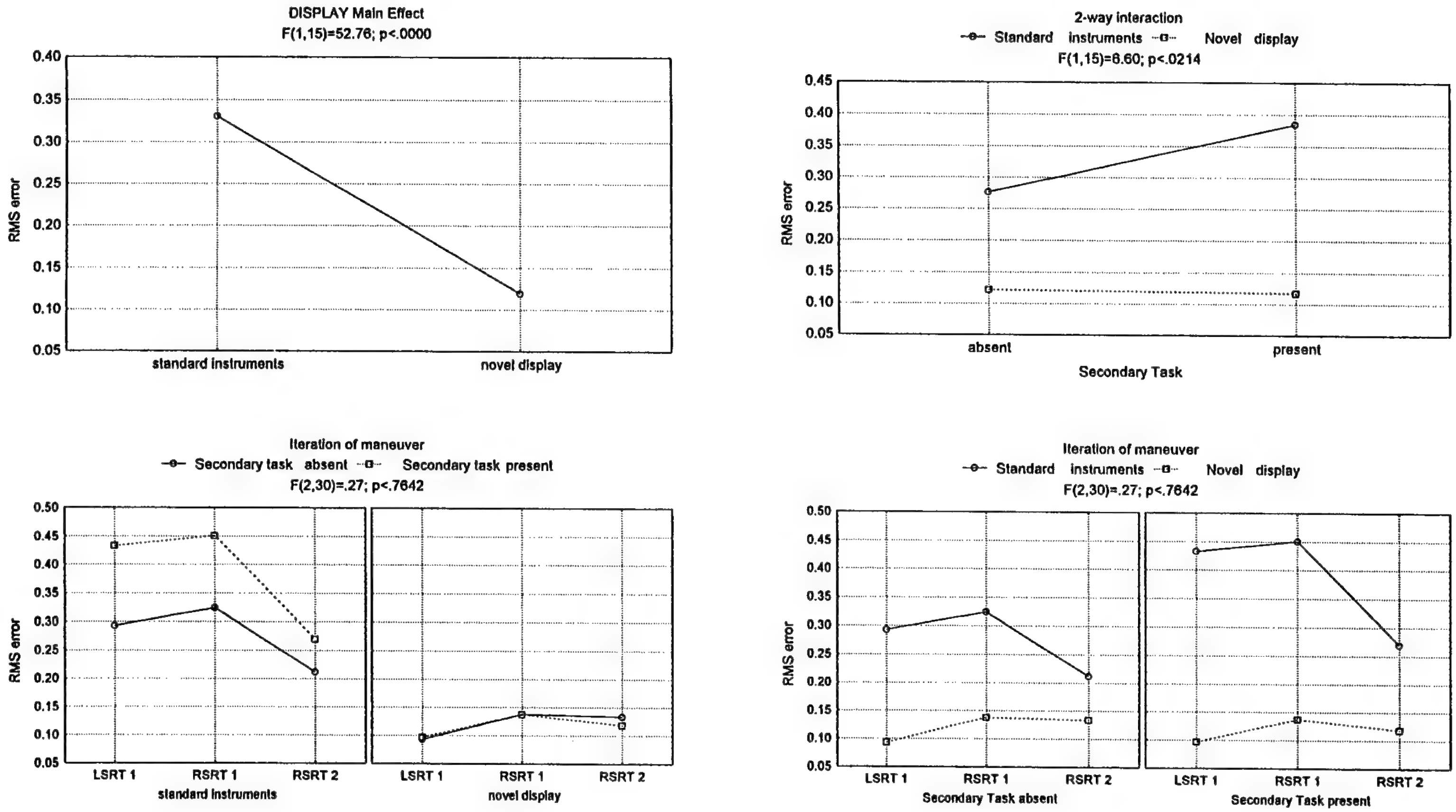


Figure 20. Maneuver = turns, parameter = turn rate, AFCS ON.

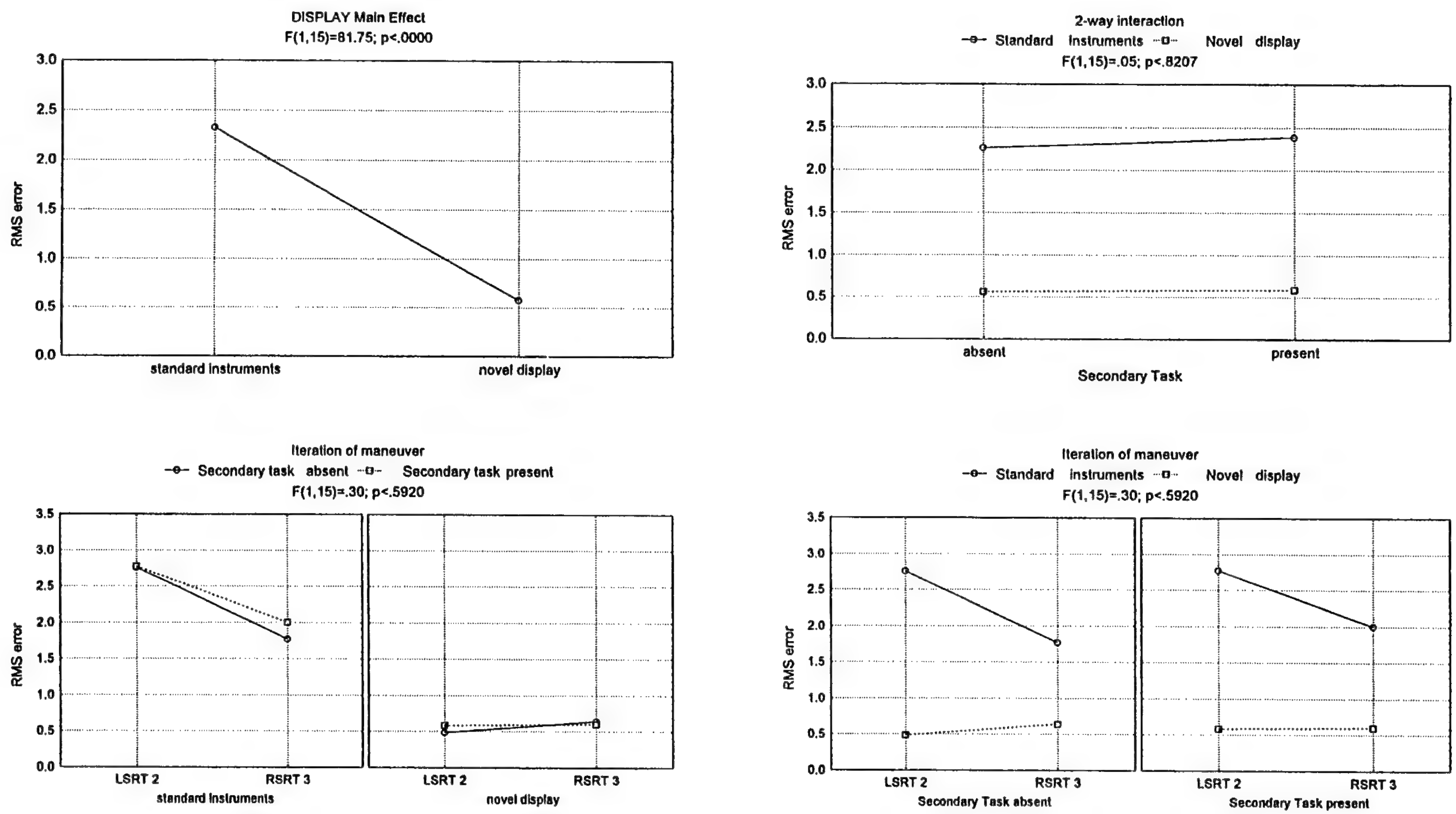


Figure 21. Maneuver = turns, parameter = airspeed, AFCS OFF.

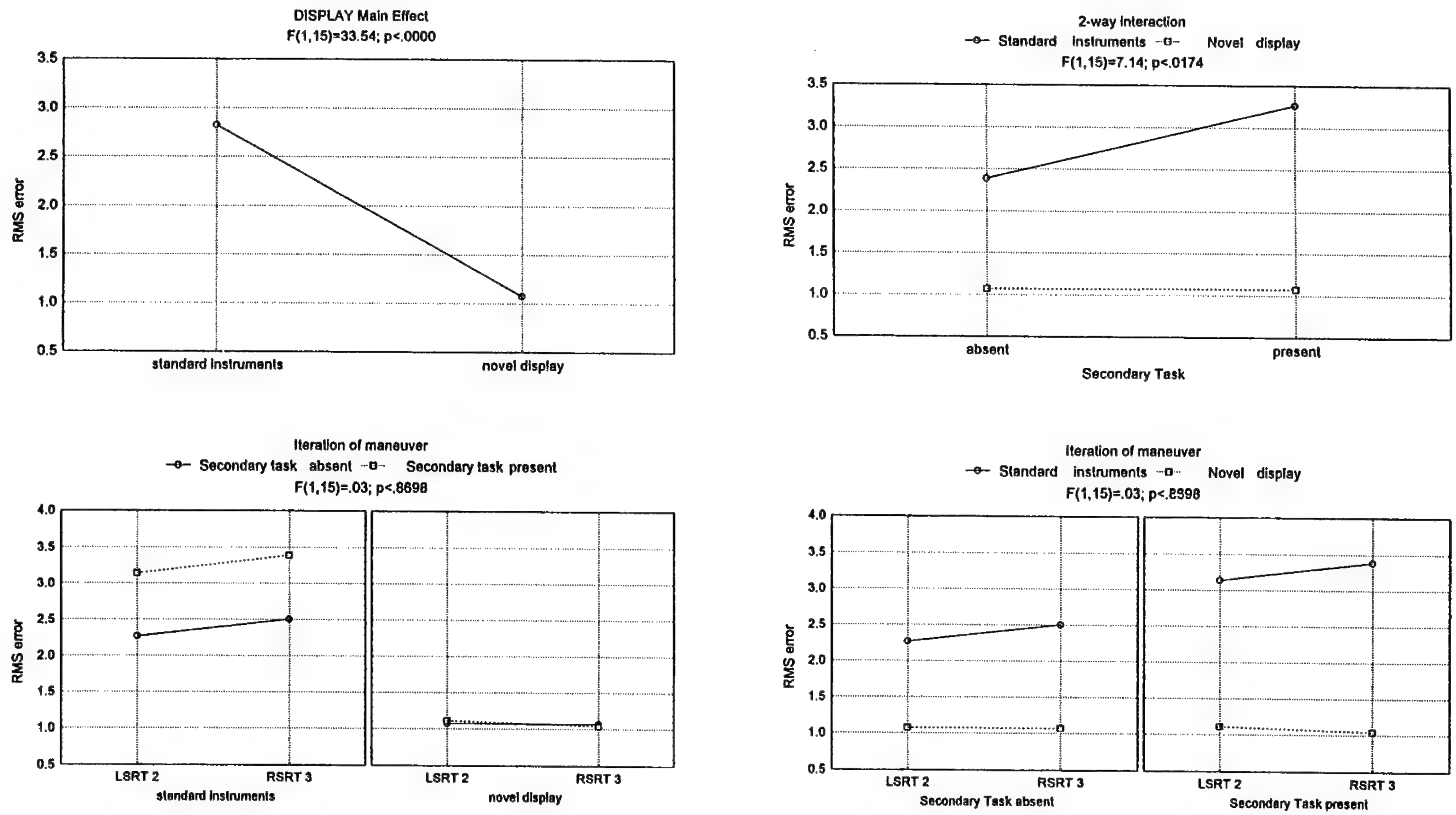


Figure 22. Maneuver = turns, parameter = roll angle, AFCS OFF.

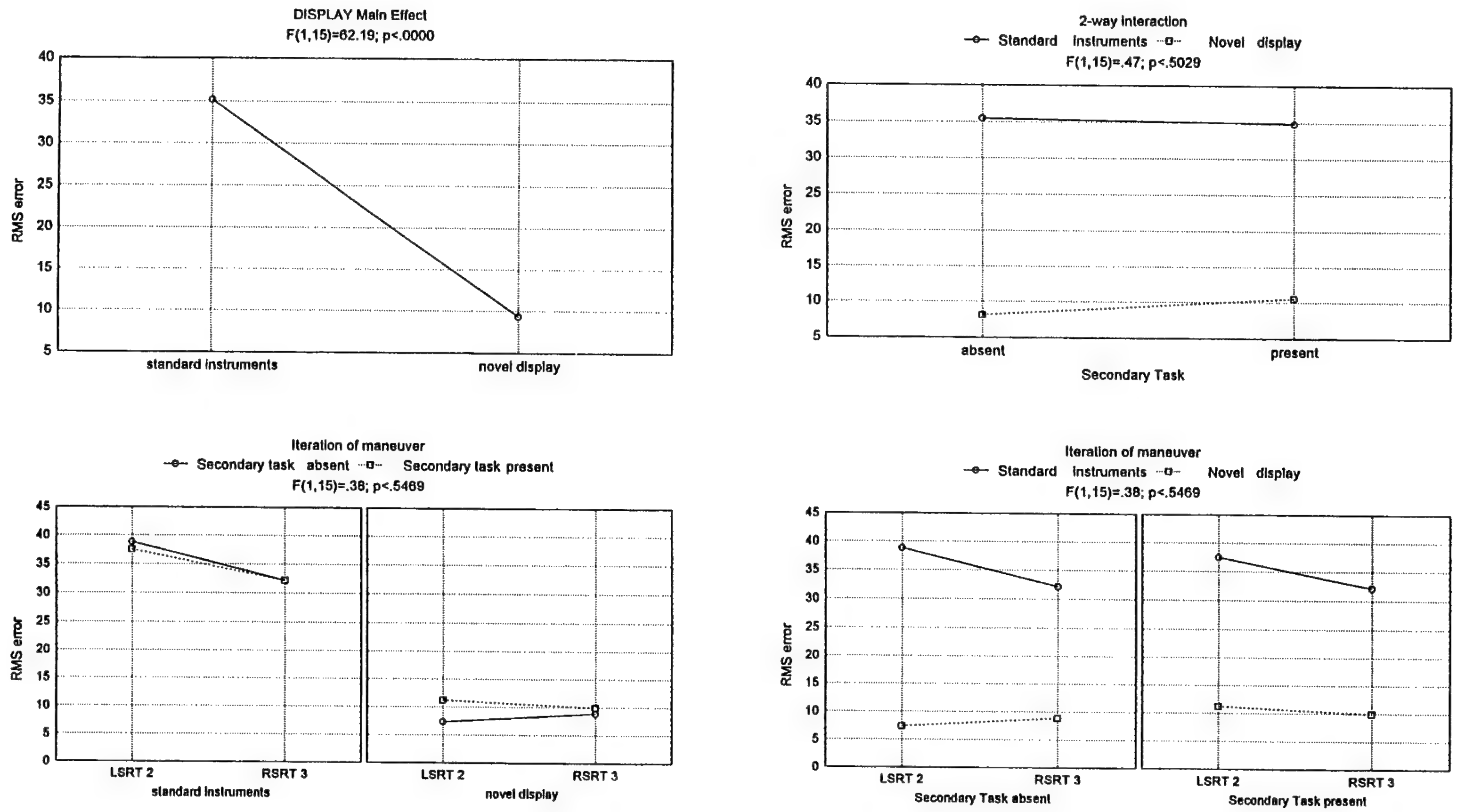


Figure 23. Maneuver = turns, parameter = altitude, AFCS OFF.

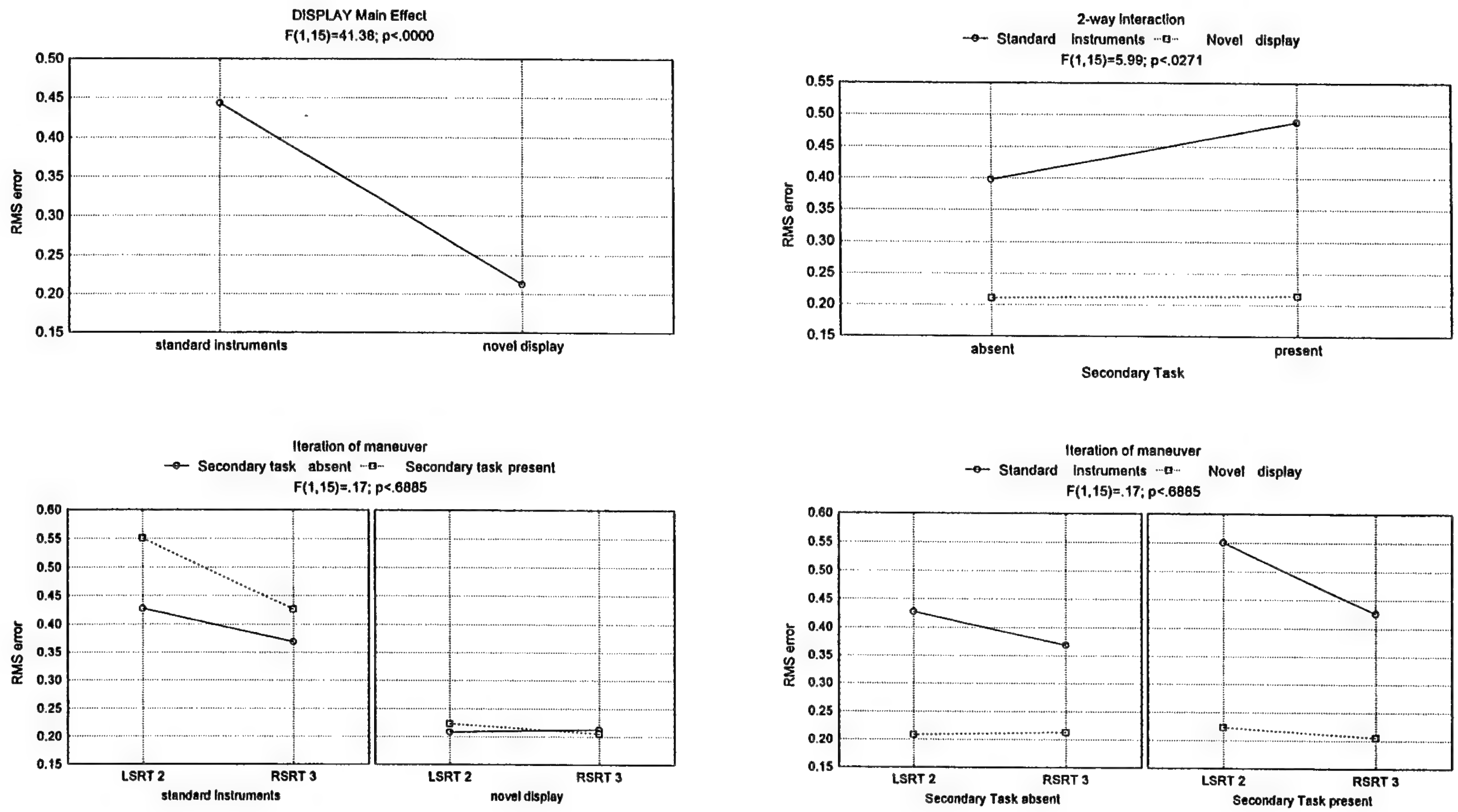


Figure 24. Maneuver = turns, parameter = turn rate, AFCS OFF.

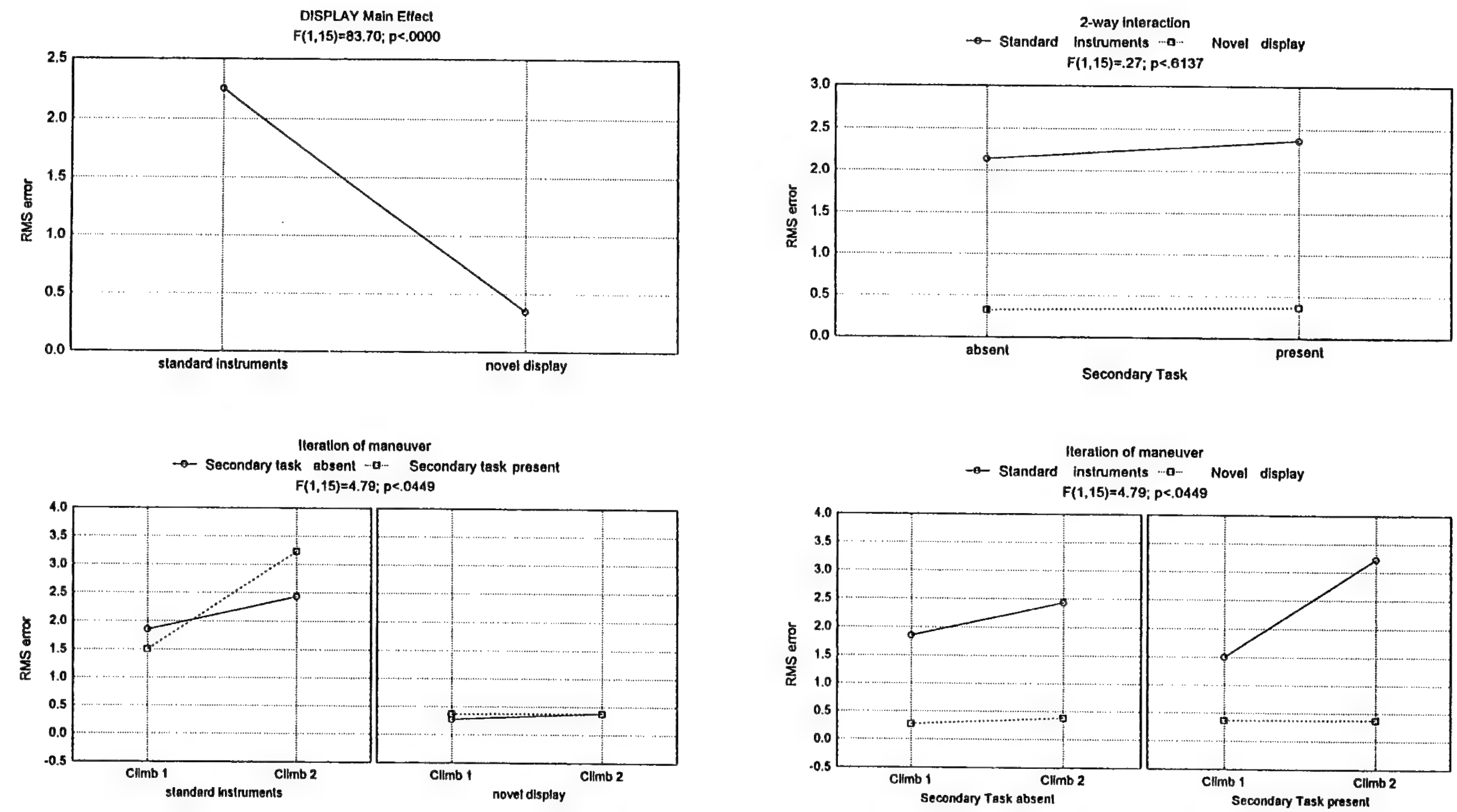


Figure 25. Maneuver = climb, parameter = airspeed, AFCS ON.

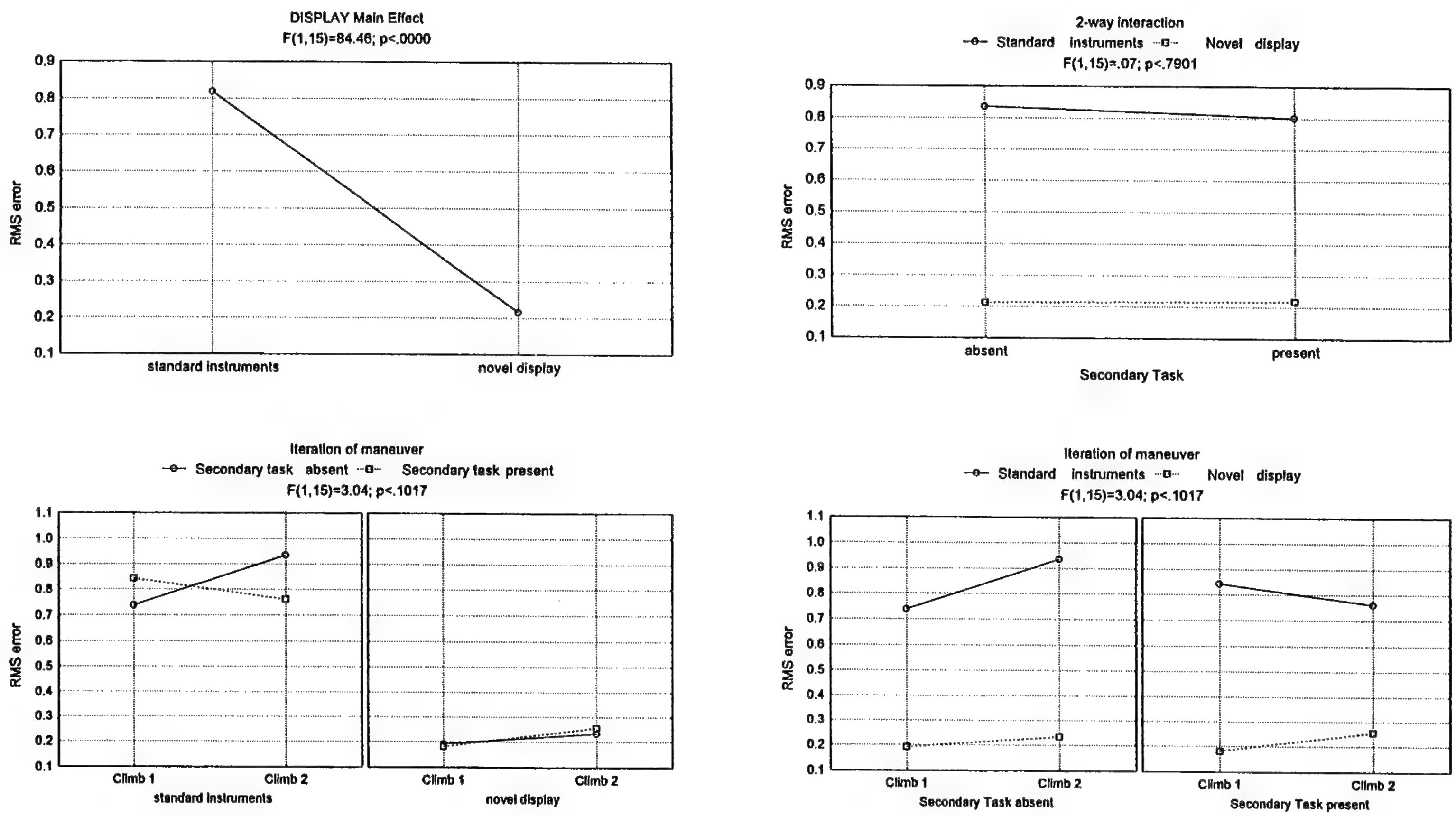


Figure 26. Maneuver = climb, parameter = roll angle, AFCS ON.

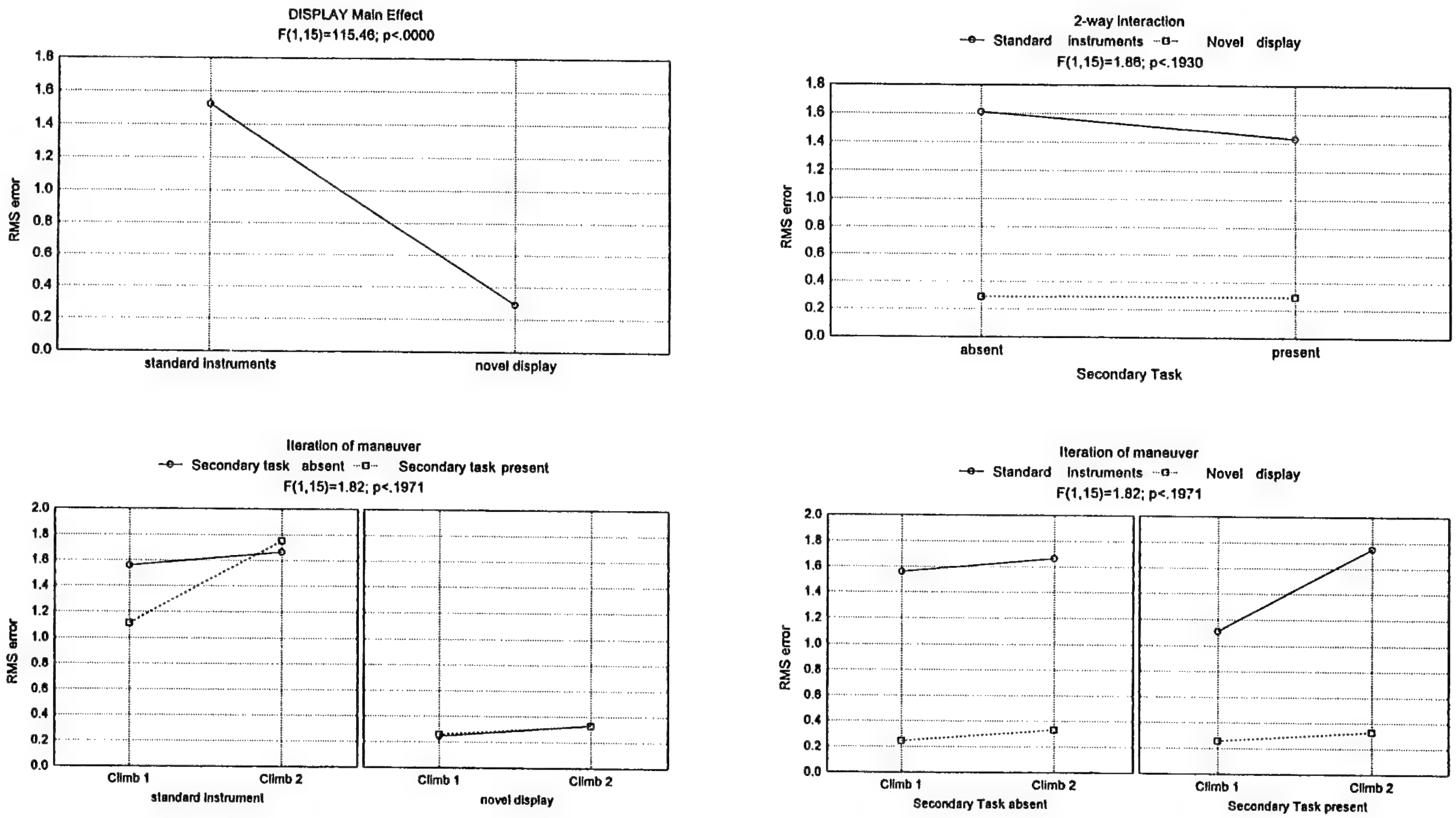


Figure 27. Maneuver = climb, parameter = heading, AFCS ON.

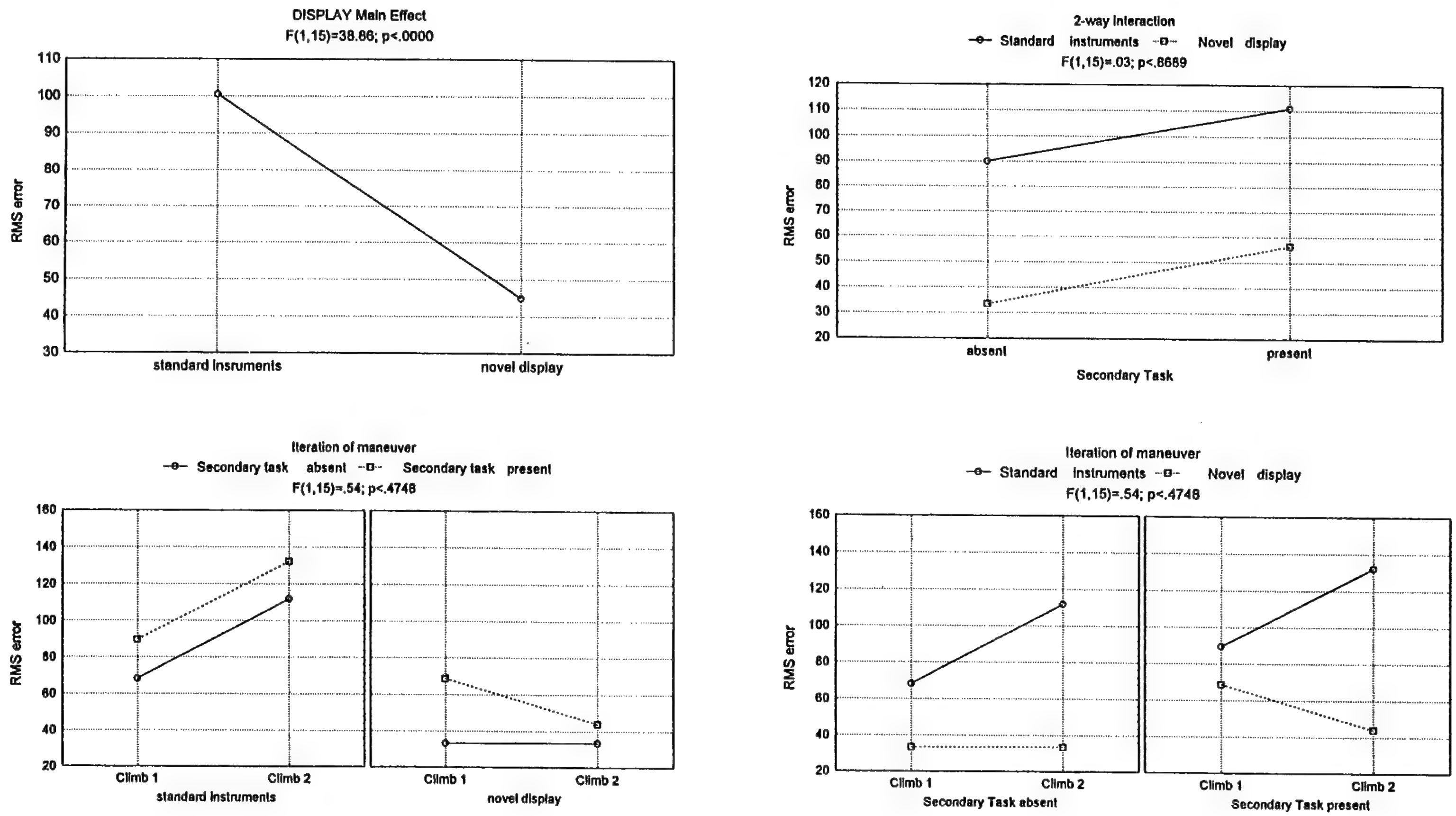


Figure 28. Maneuver = climb, parameter = rate of climb, AFCS ON.

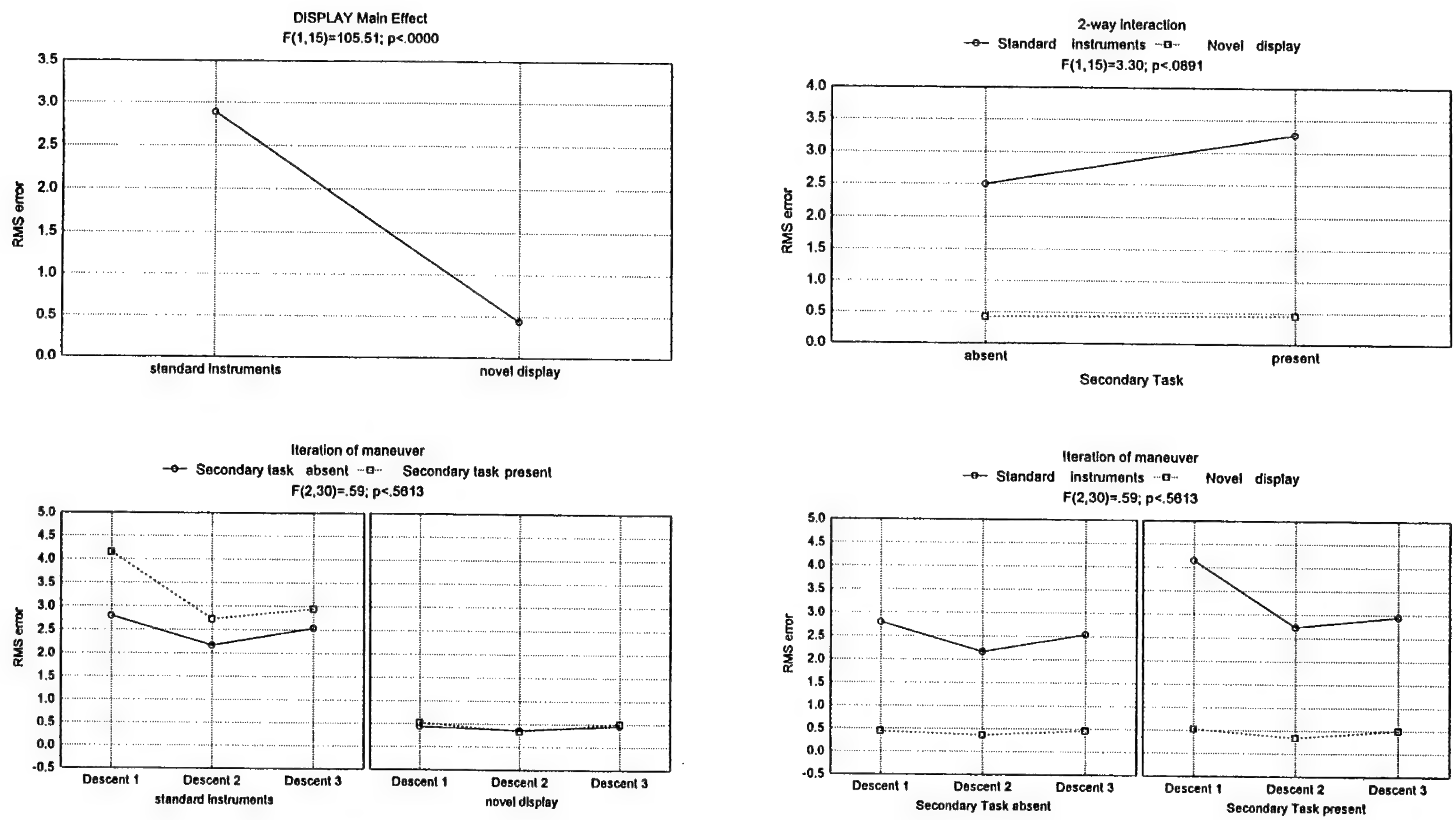


Figure 29. Maneuver = descent, parameter = airspeed, AFCS OFF.

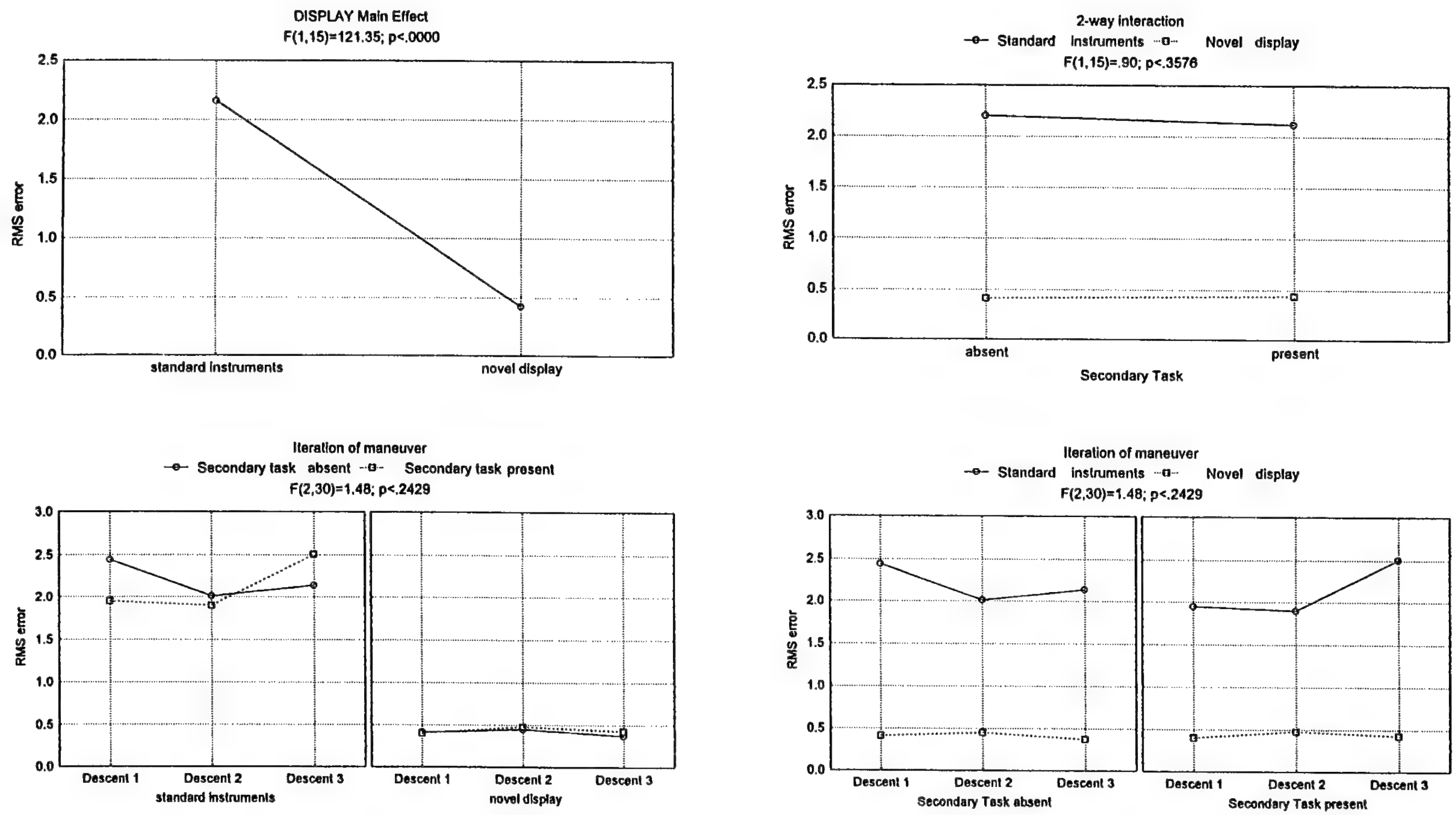


Figure 30. Maneuver = descent, parameter = roll angle, AFCS OFF.

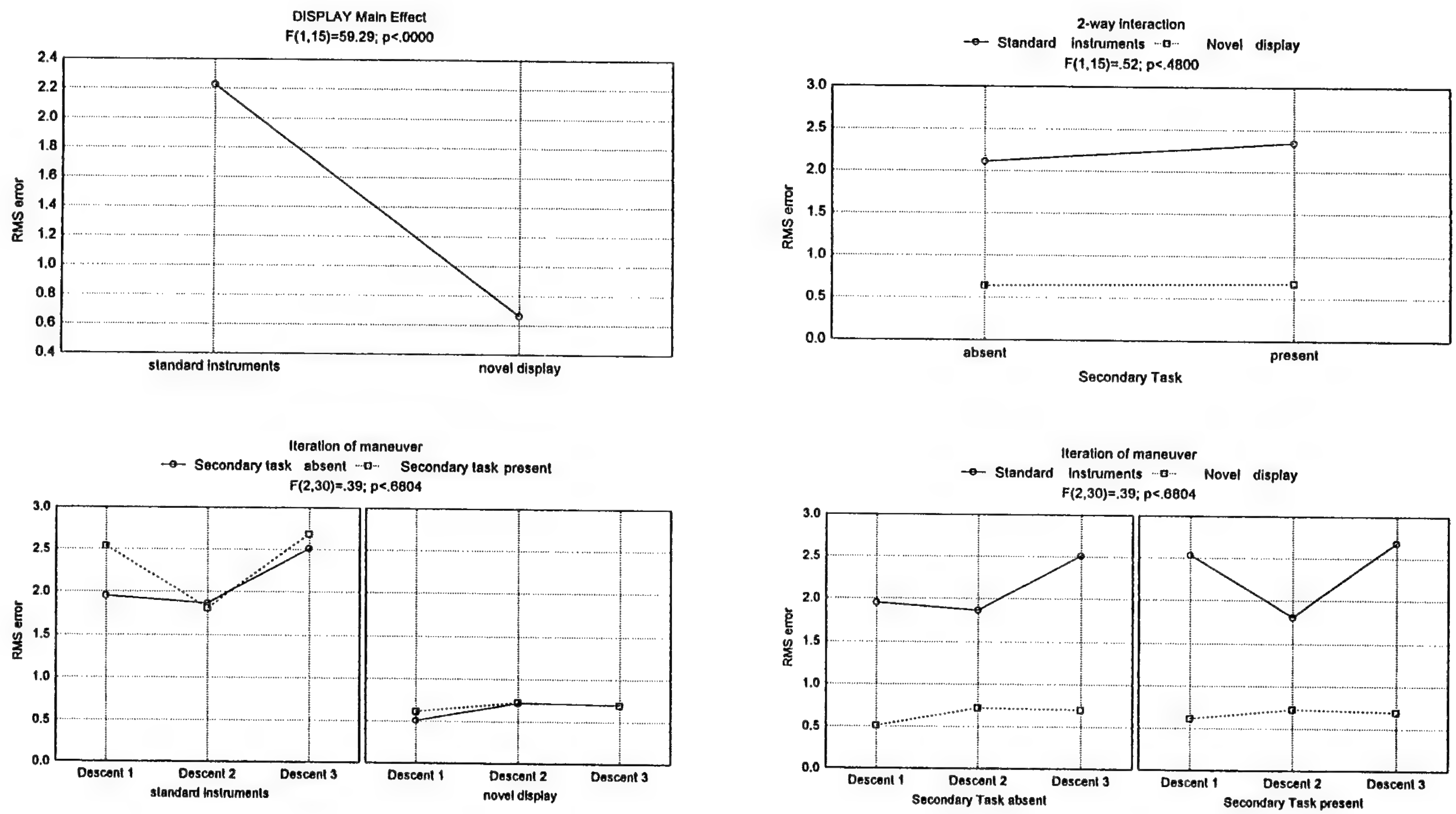


Figure 31. Maneuver = descent, parameter = heading, AFCS OFF.

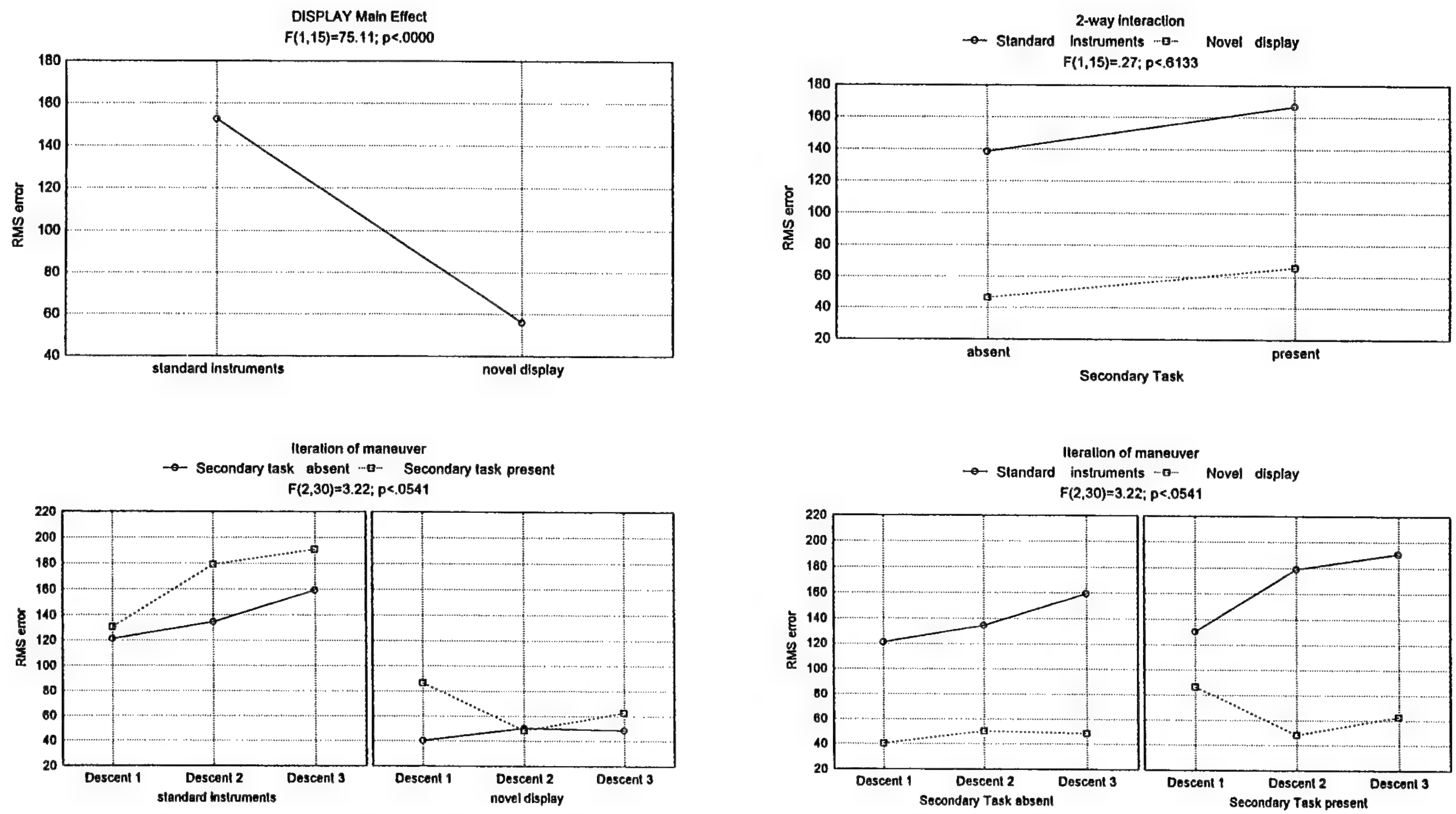


Figure 32. Maneuver = descent, parameter = rate of descent, AFCS OFF.

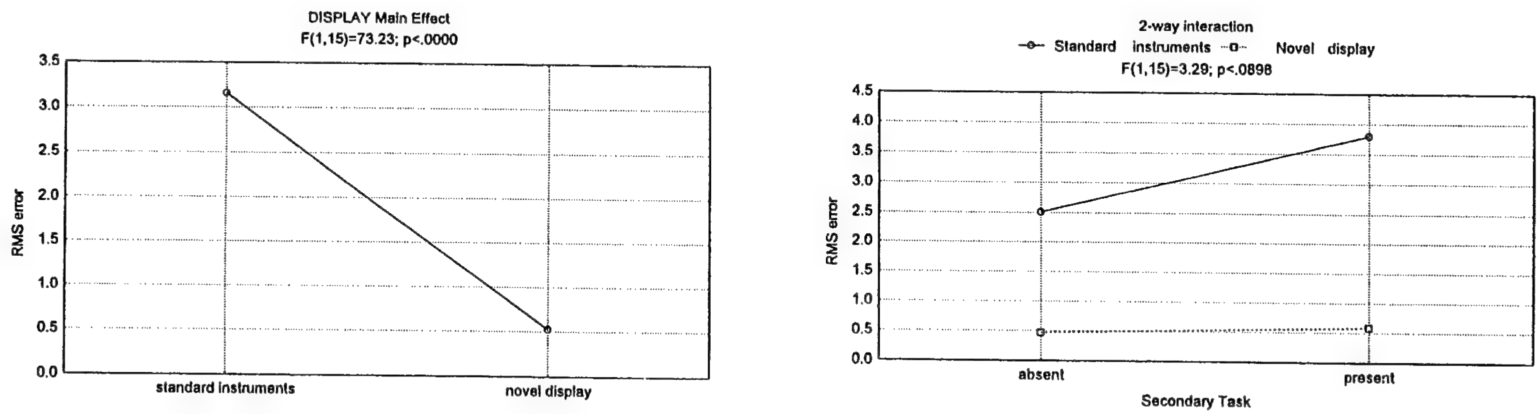


Figure 33. Maneuver = left descending turn, parameter = airspeed, AFCS OFF.

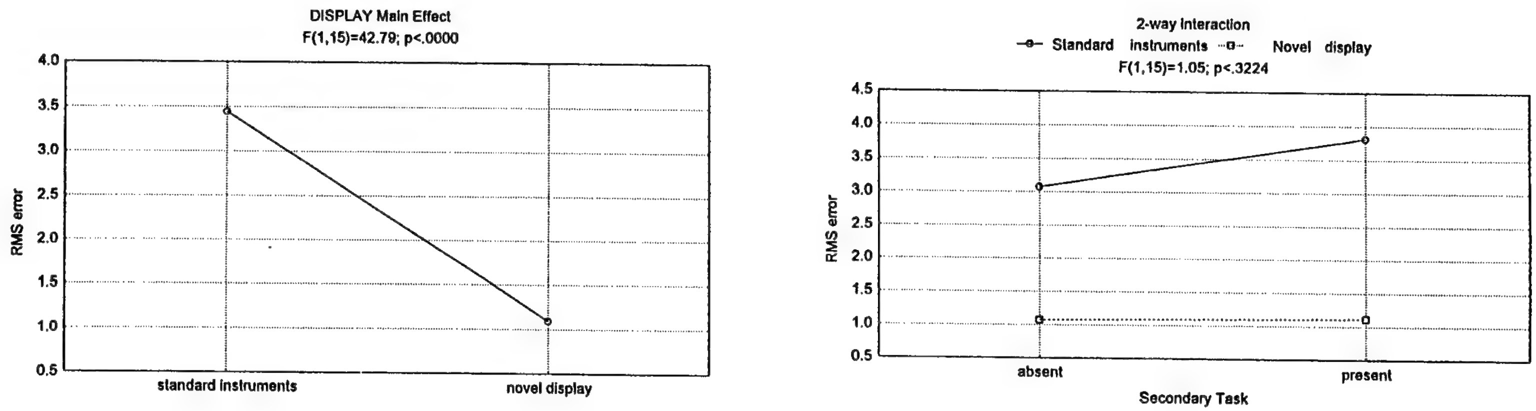


Figure 34. Maneuver = left descending turn, parameter = roll angle, AFCS OFF.

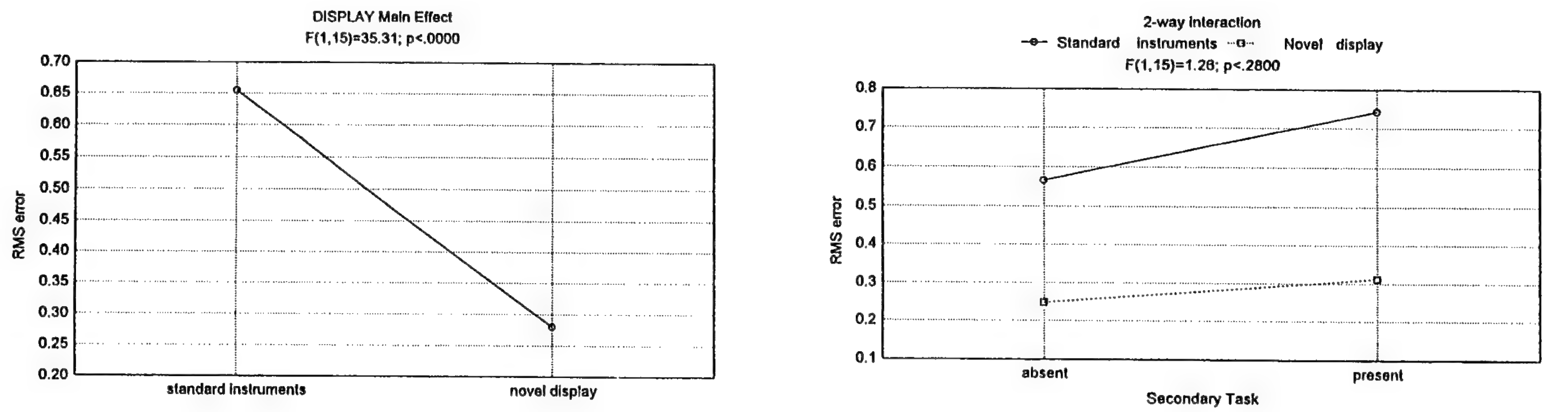


Figure 35. Maneuver = left descending turn, parameter = turn rate, AFCS OFF.

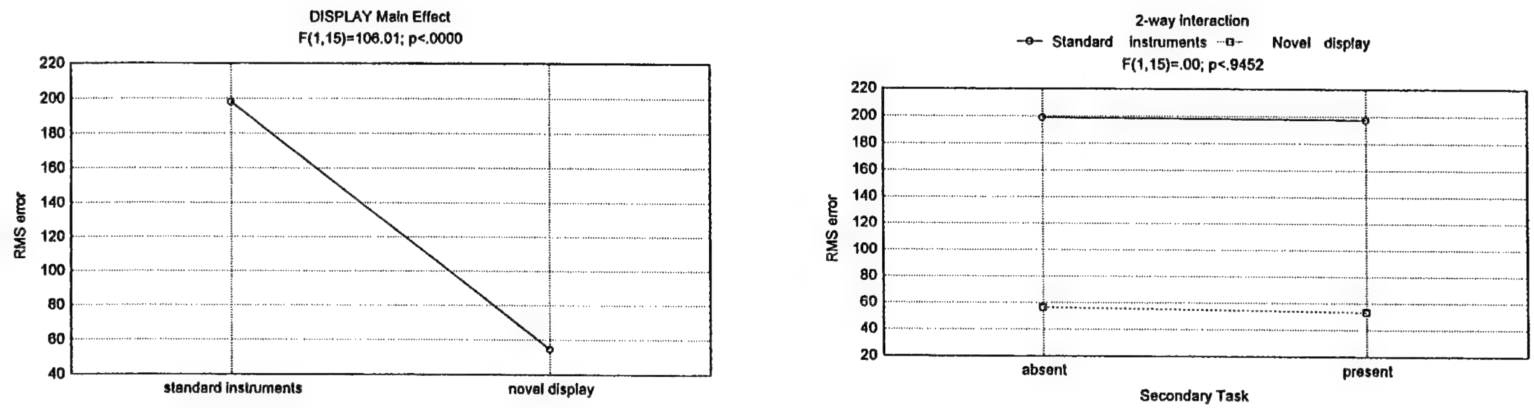


Figure 36. Maneuver = left descending turn, parameter = rate of descent, AFCS OFF.

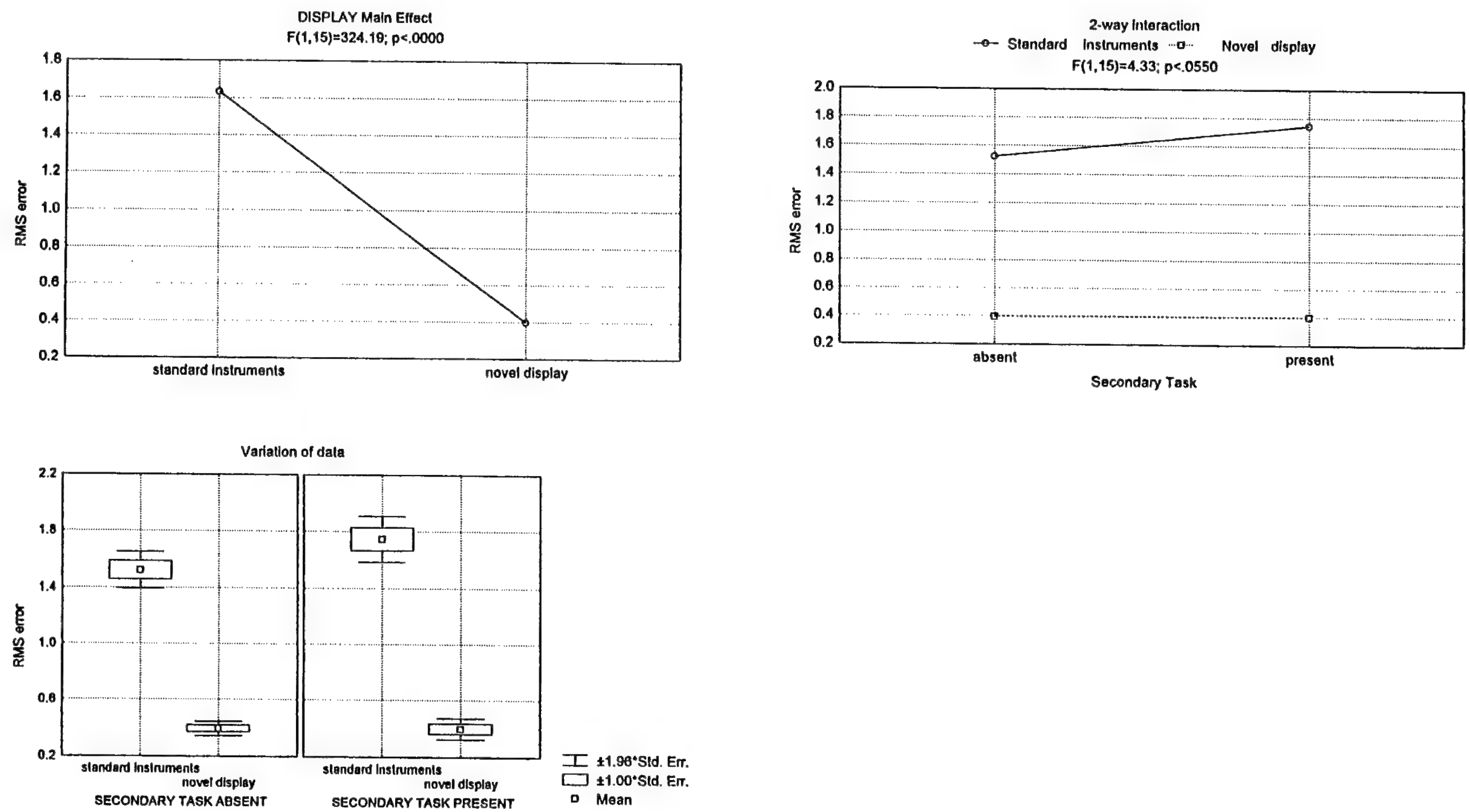


Figure 37. Parameter = airspeed for all maneuvers, AFCS ON.

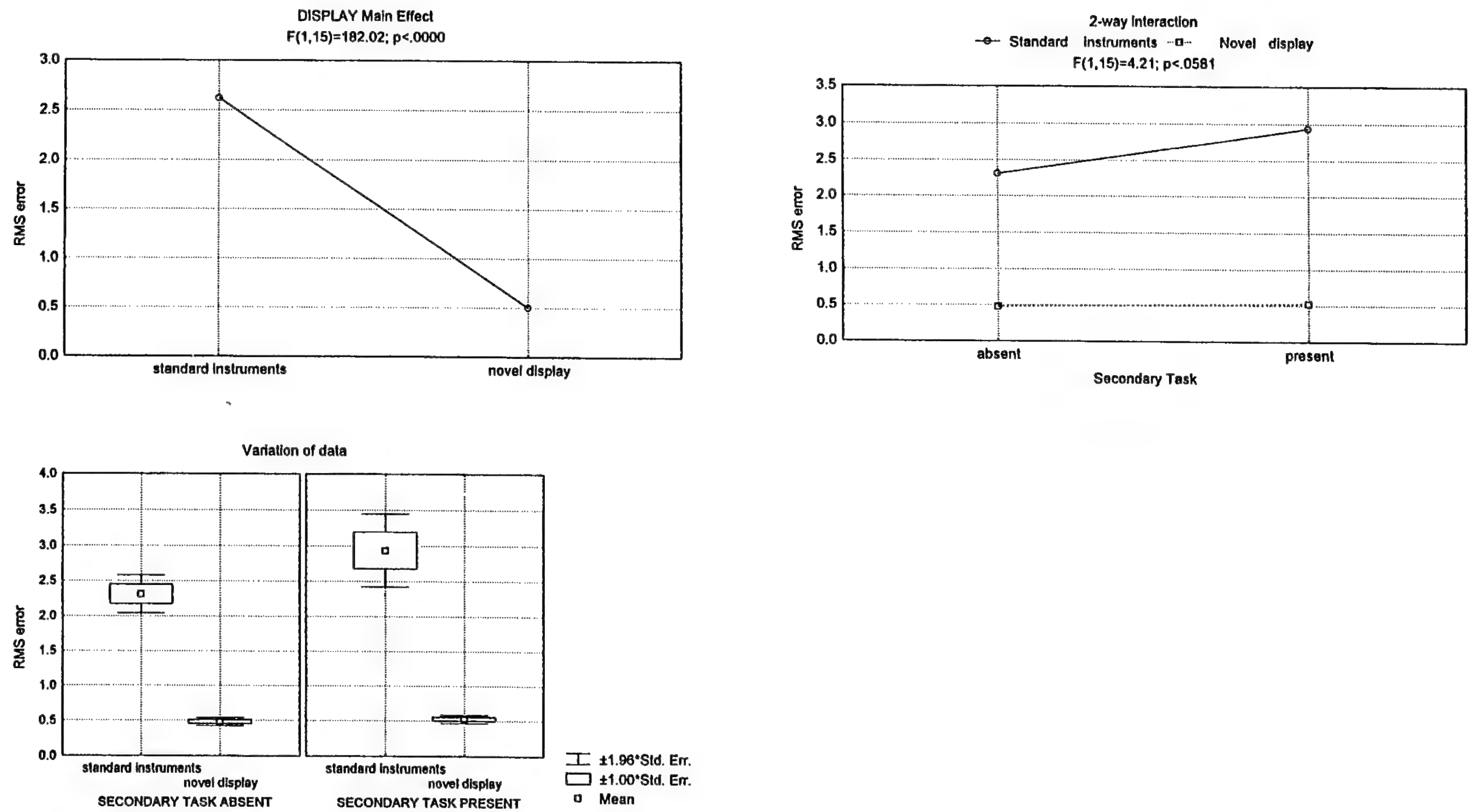


Figure 38. Parameter = airspeed for all maneuvers, AFCS OFF.

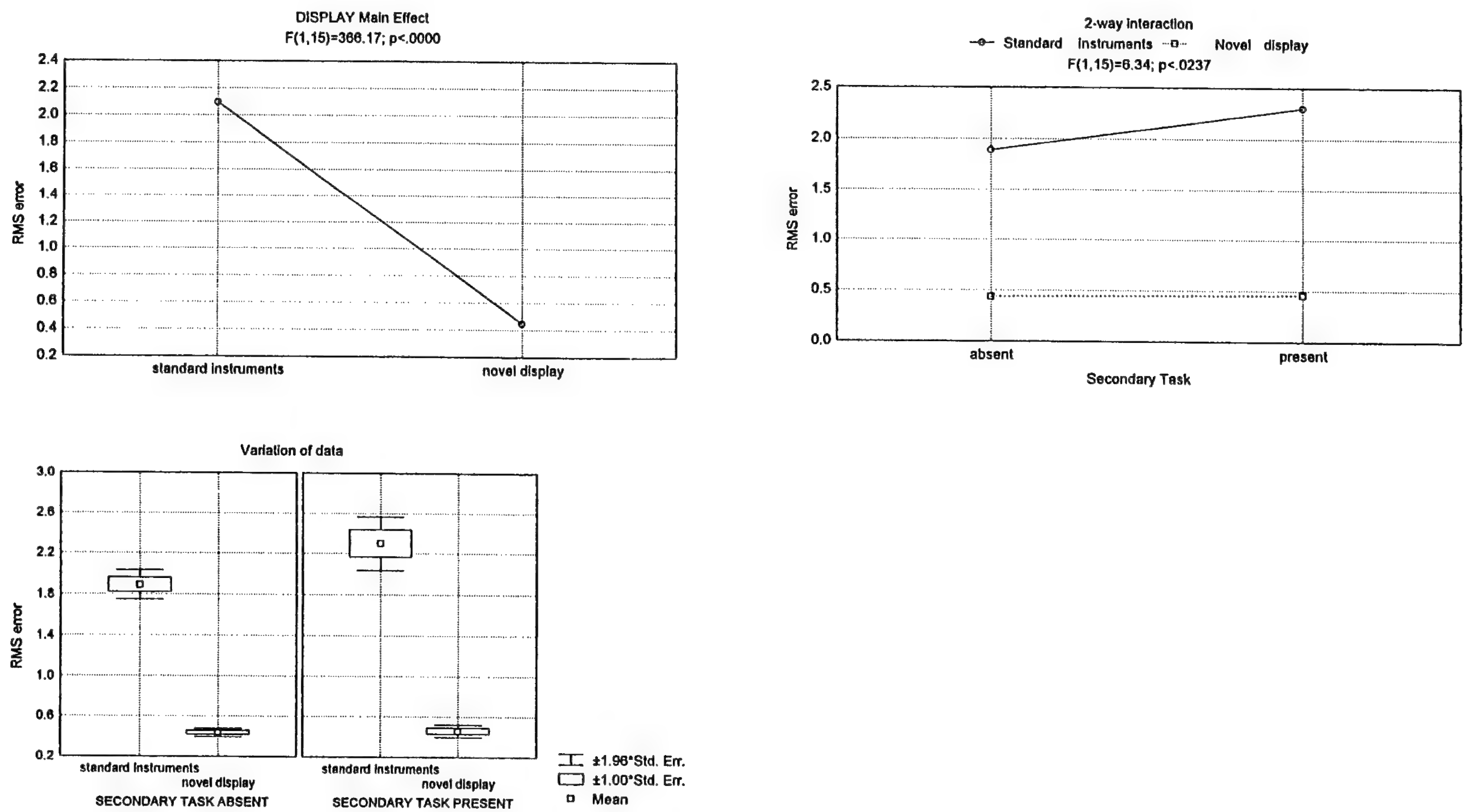


Figure 39. Parameter = airspeed for all maneuvers, AFCS ON and OFF.

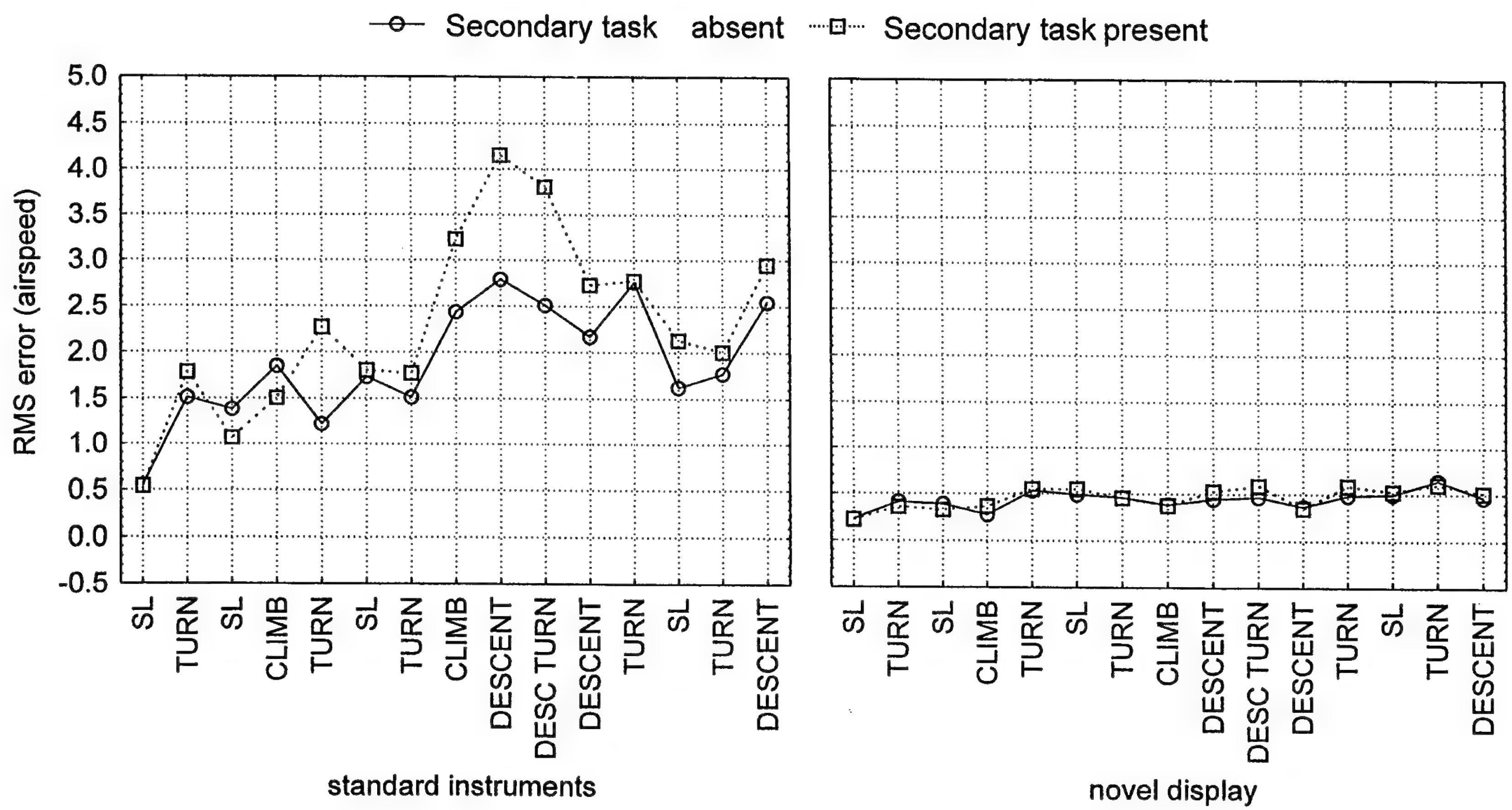


Figure 40. RMS error of airspeed for all maneuvers by display type.

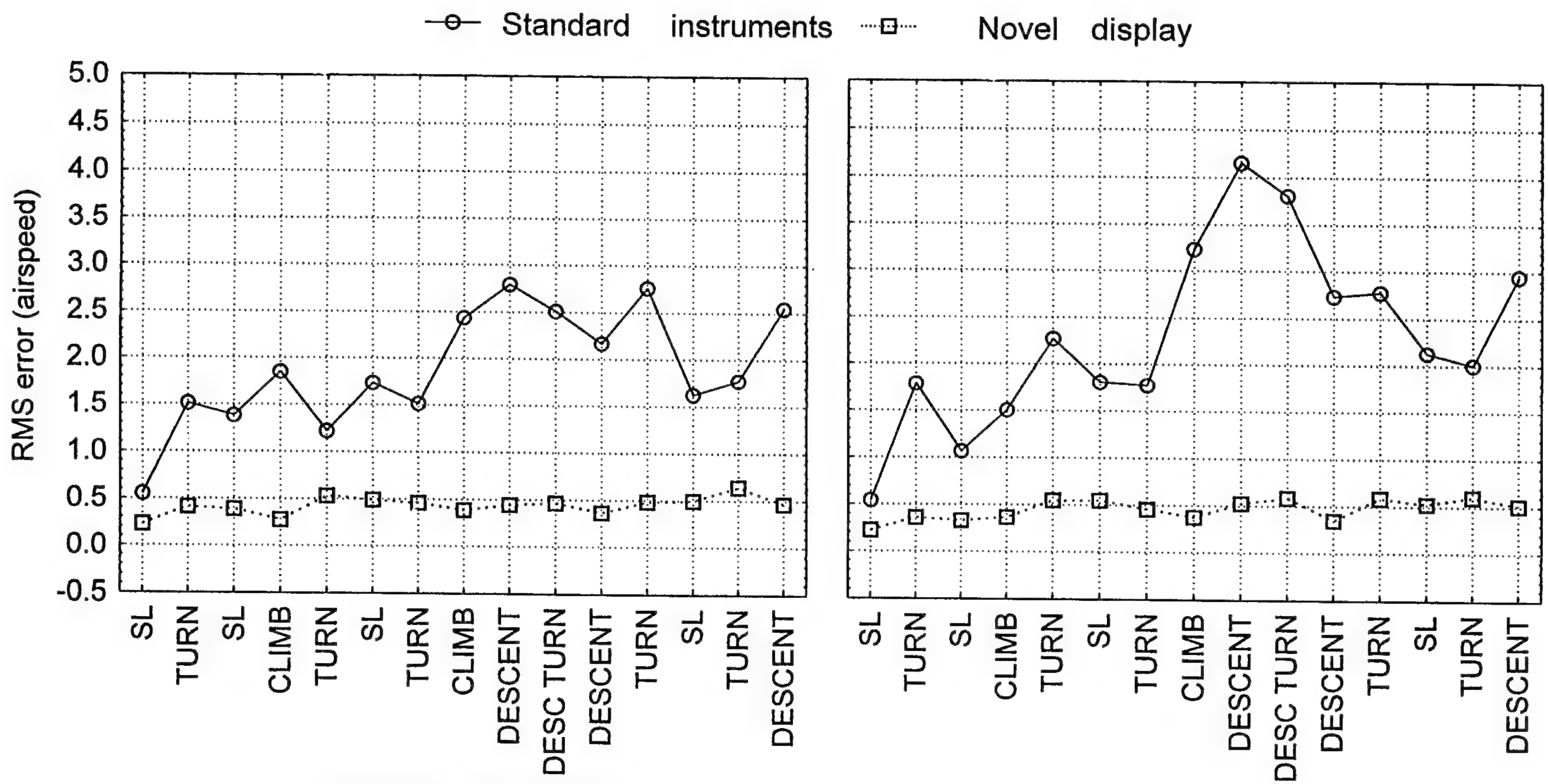


Figure 41. RMS error of airspeed for all maneuvers by secondary task.

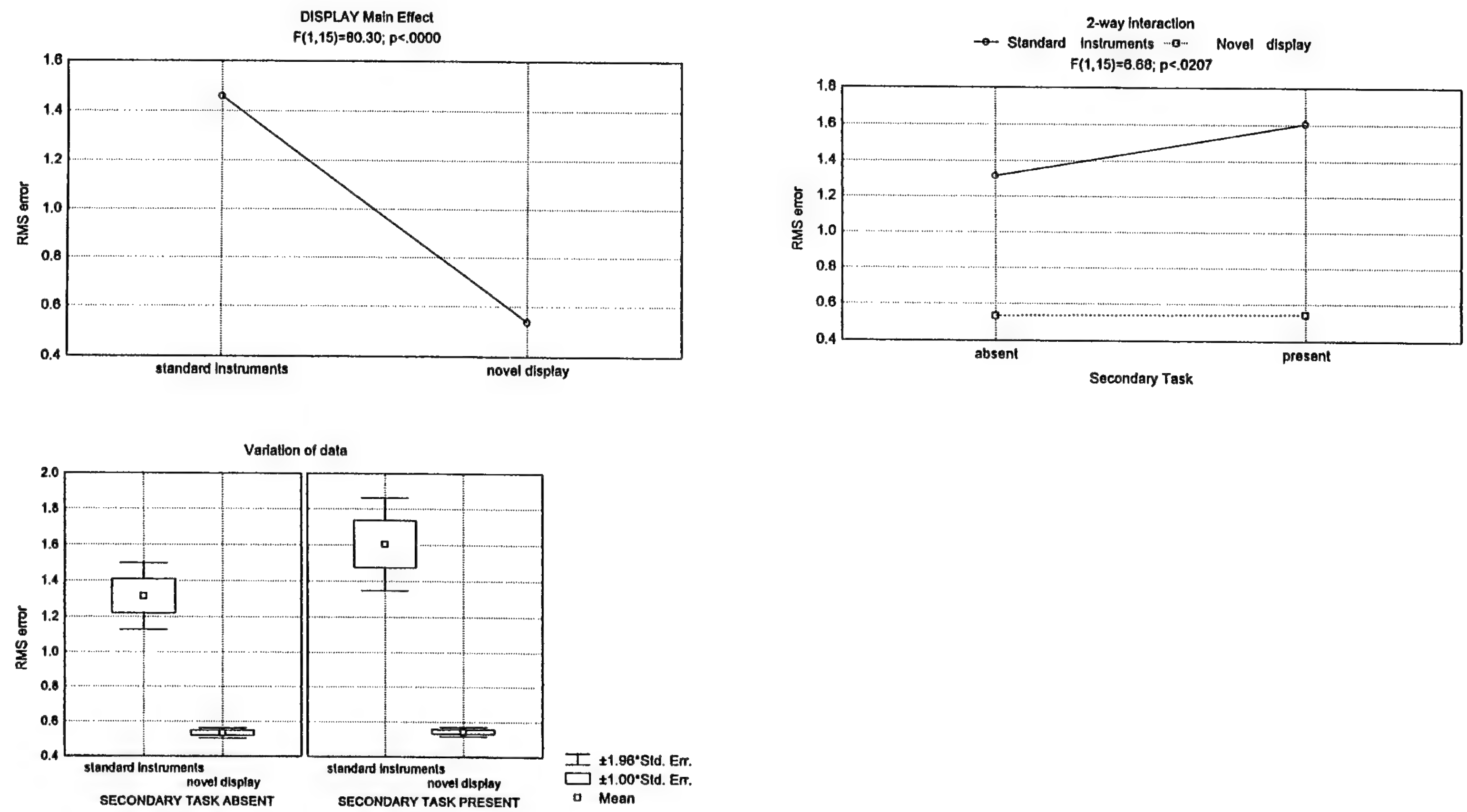


Figure 42. Parameter = roll angle for all maneuvers, AFCS ON.

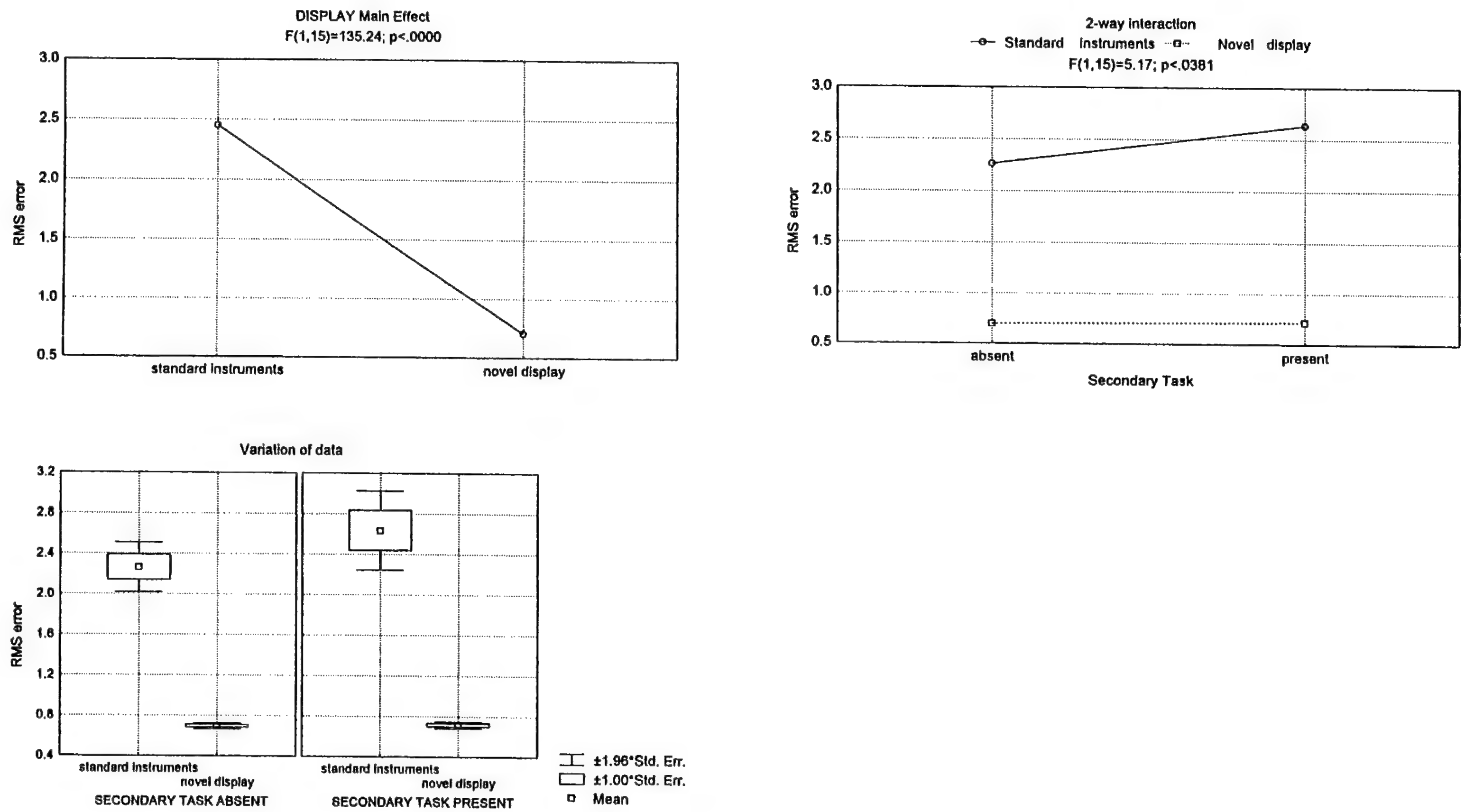


Figure 43. Parameter = roll angle for all maneuvers, AFCS OFF.

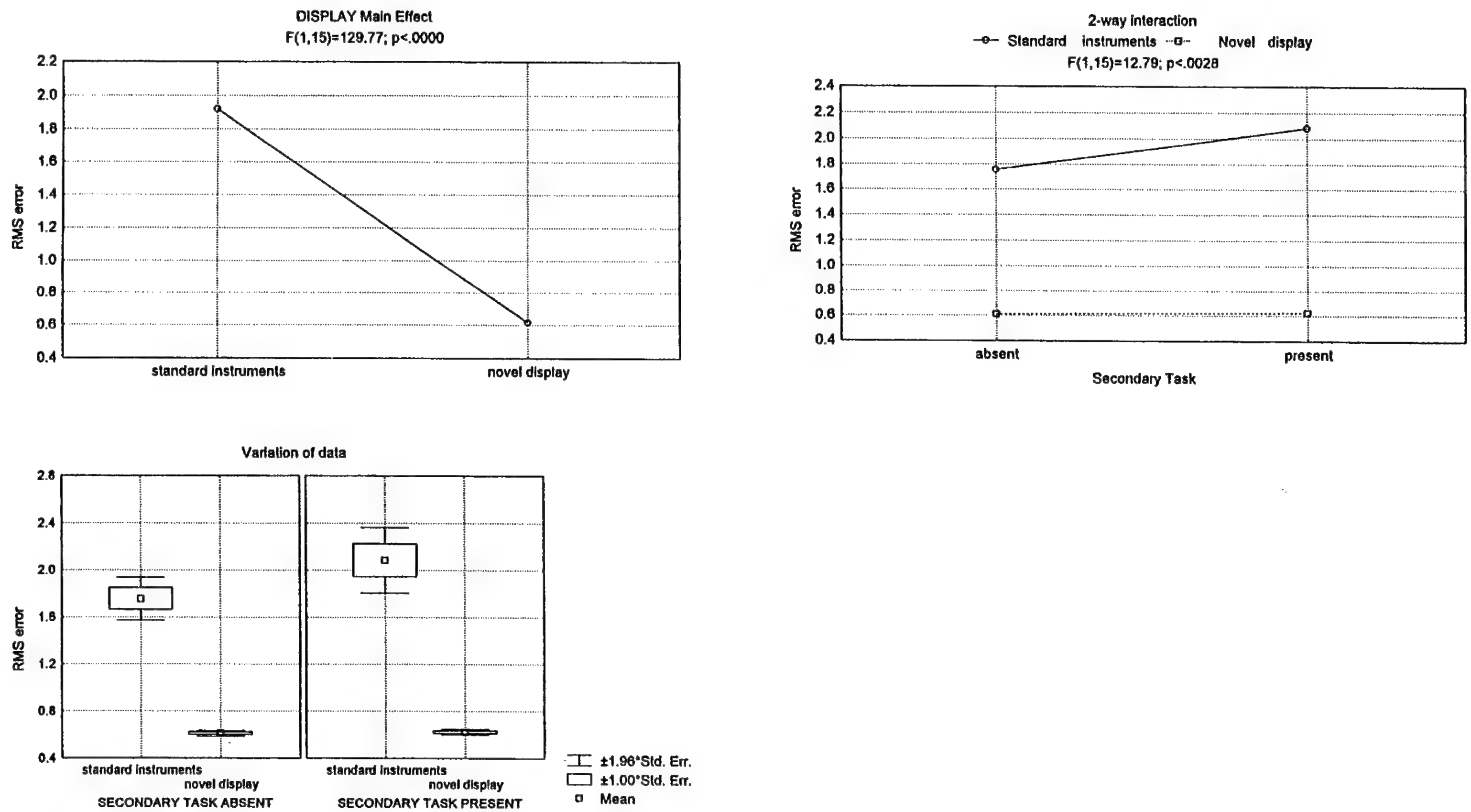


Figure 44. Parameter = roll angle for all maneuvers, AFCS ON and OFF.

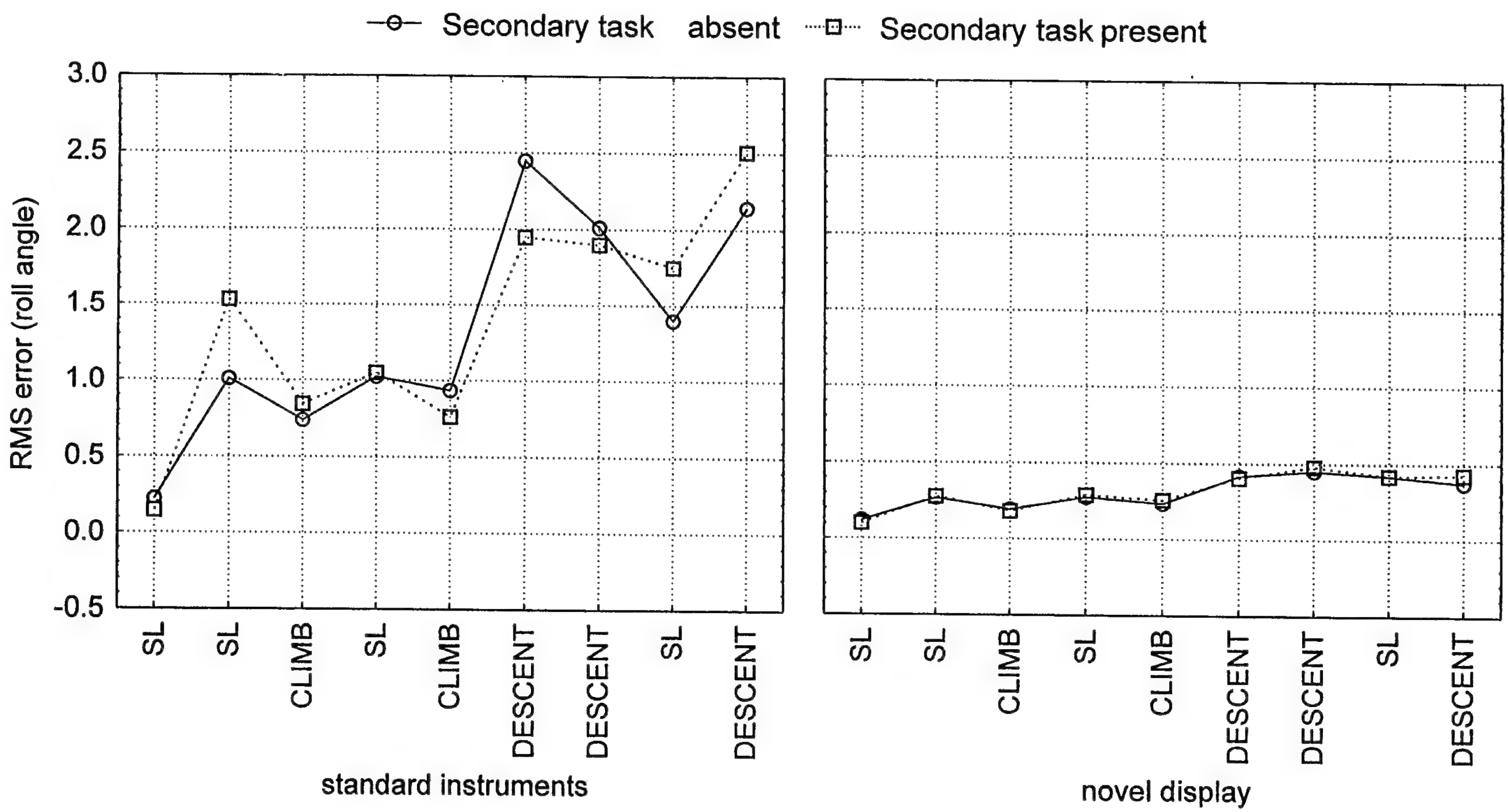


Figure 45. RMS error of roll angle for non-turning maneuvers by display type.

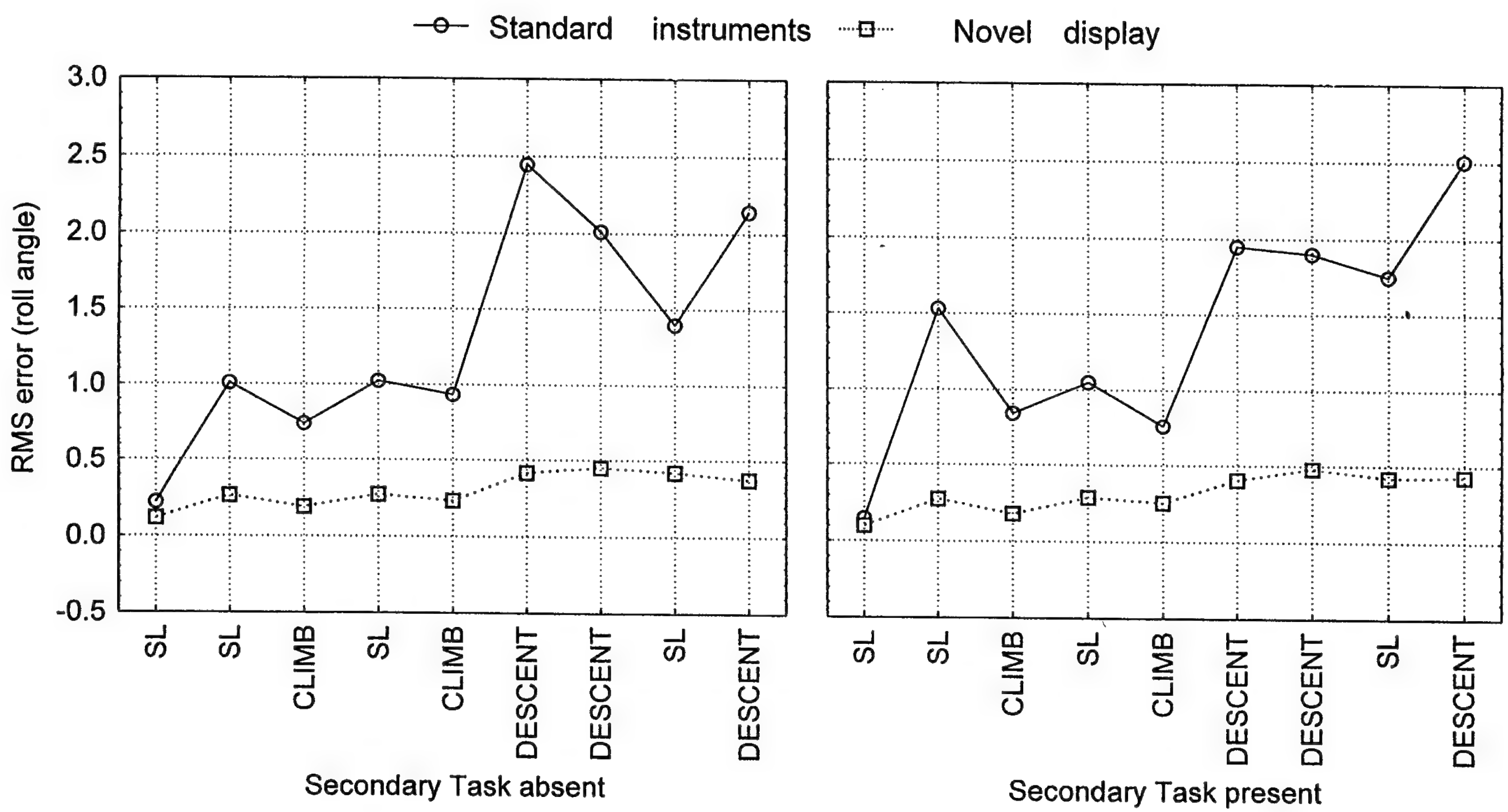


Figure 46. RMS error of roll angle for non-turning maneuvers by secondary task.

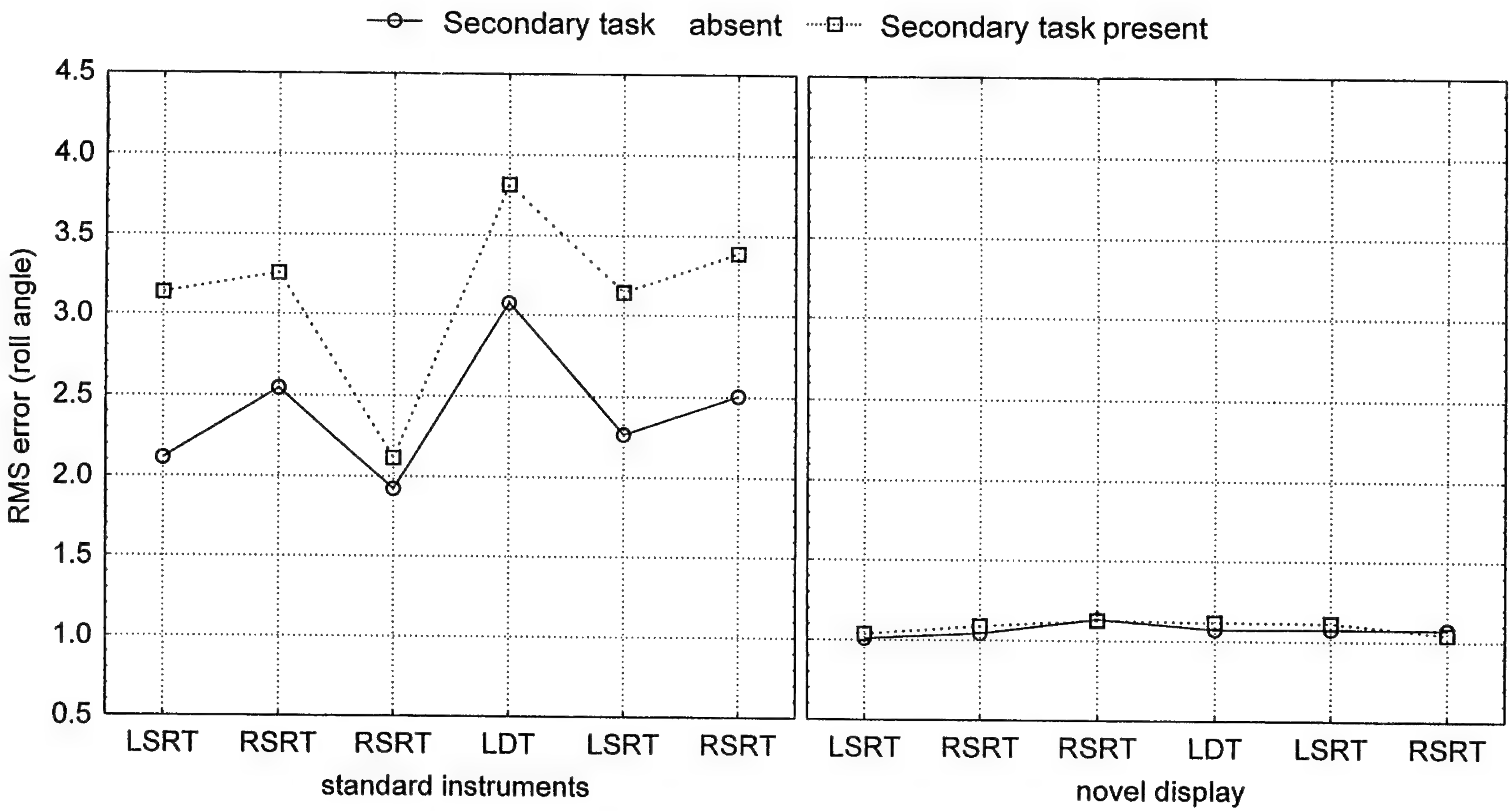


Figure 47. RMS error of roll angle for turning maneuvers by display type.

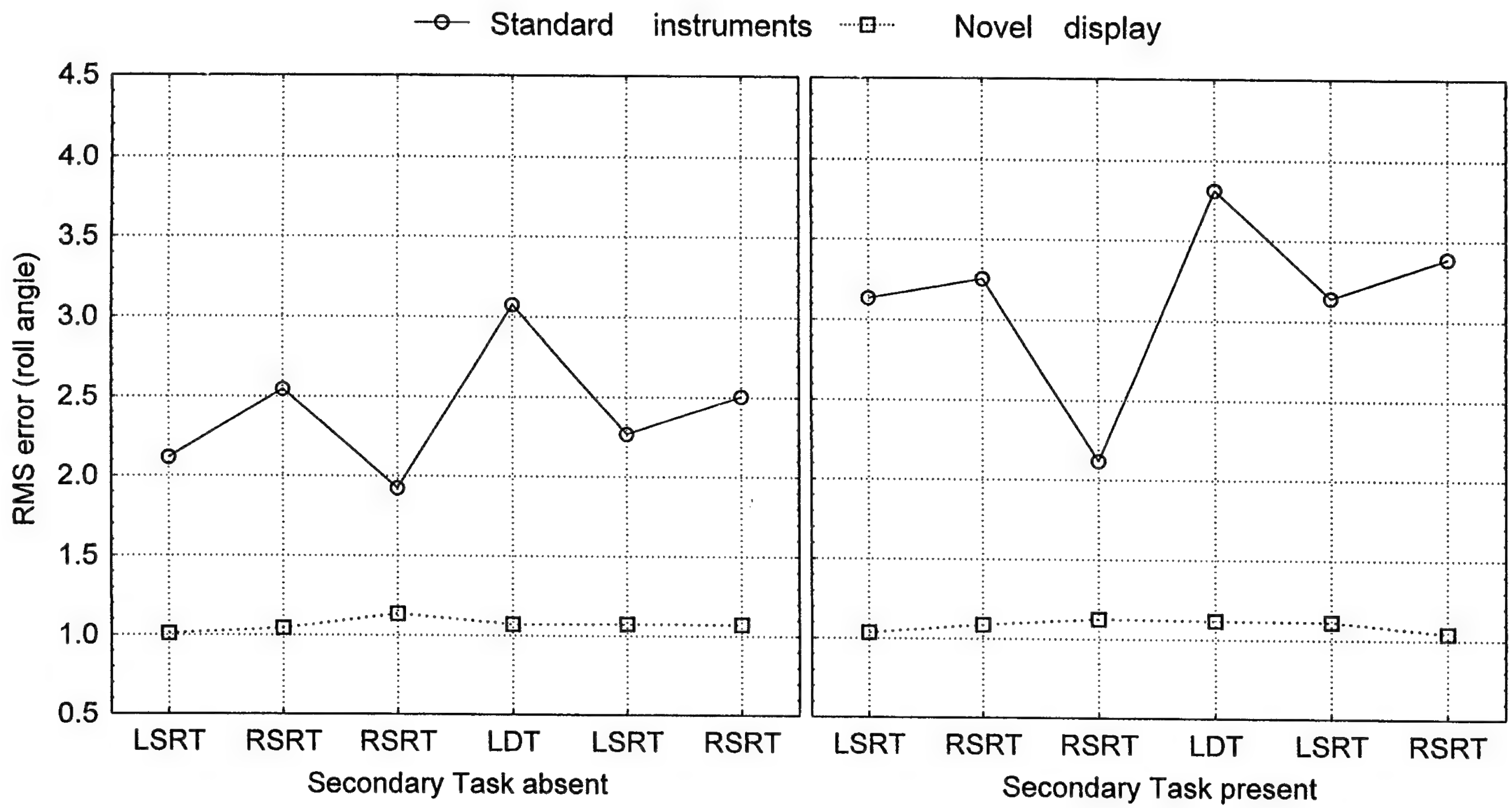


Figure 48. RMS error of roll angle for turning maneuvers by secondary task.

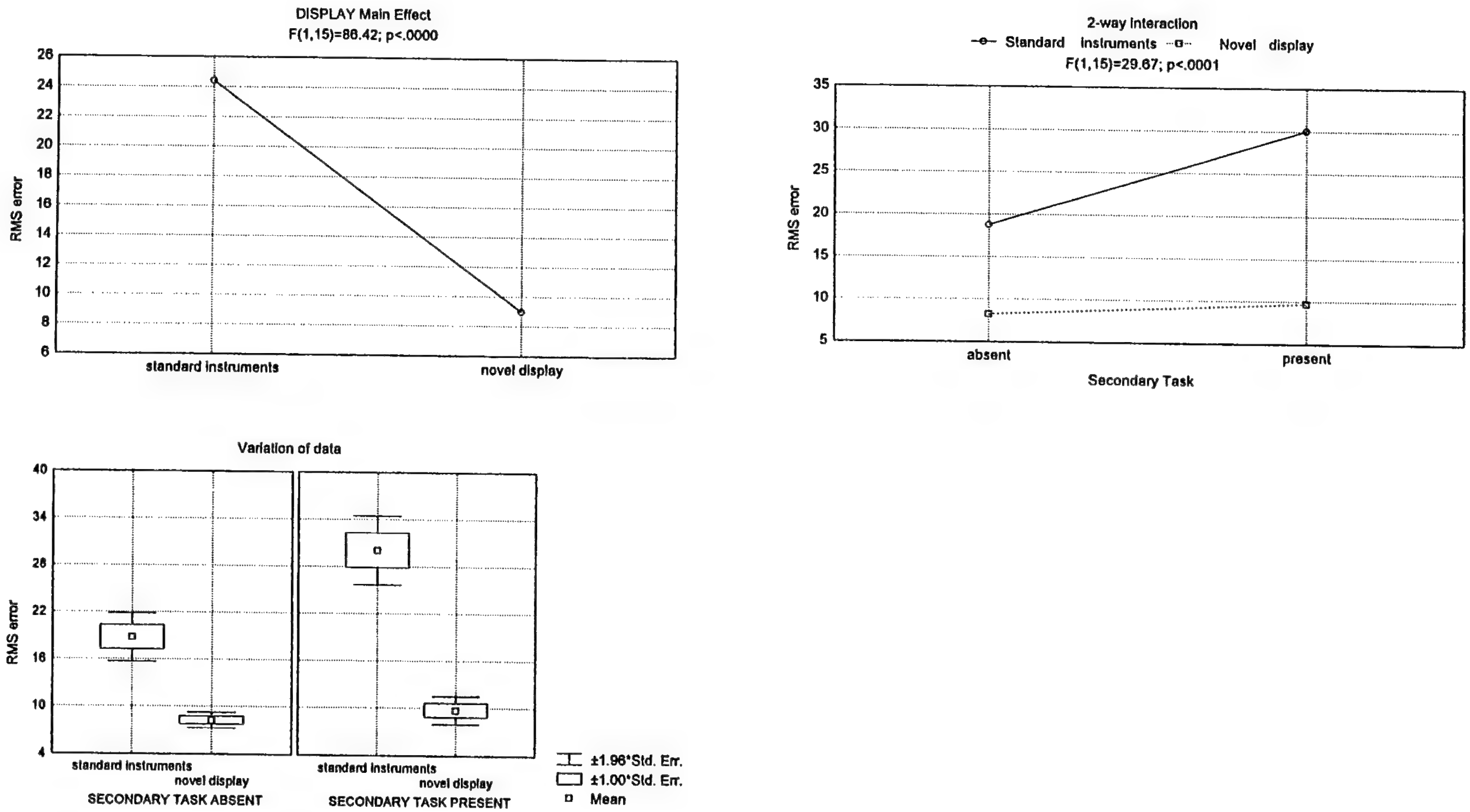


Figure 49. Parameter = altitude for all maneuvers (less climbs and descents), AFCS ON.

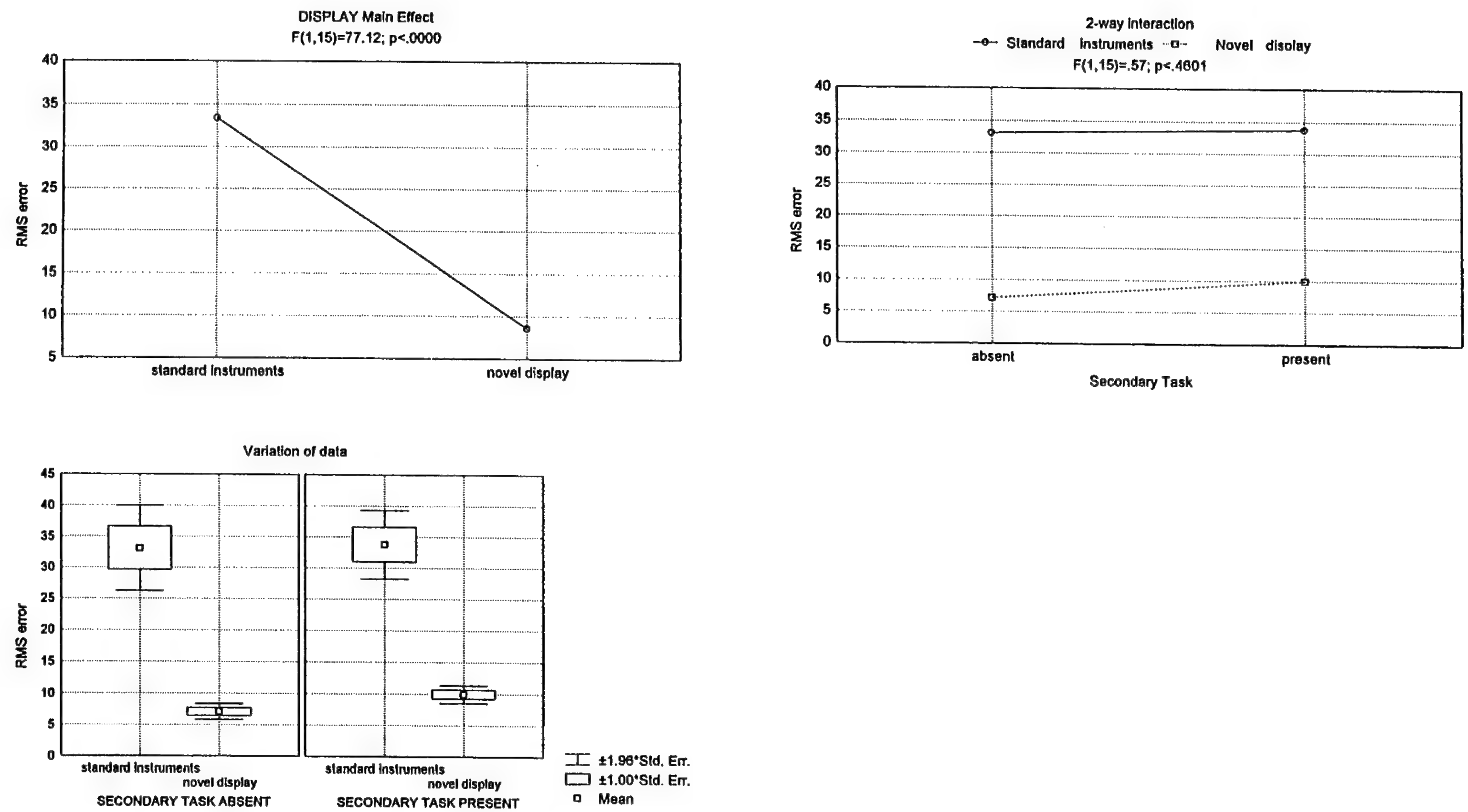


Figure 50. Parameter = altitude for all maneuvers (less climbs and descents), AFCS OFF.

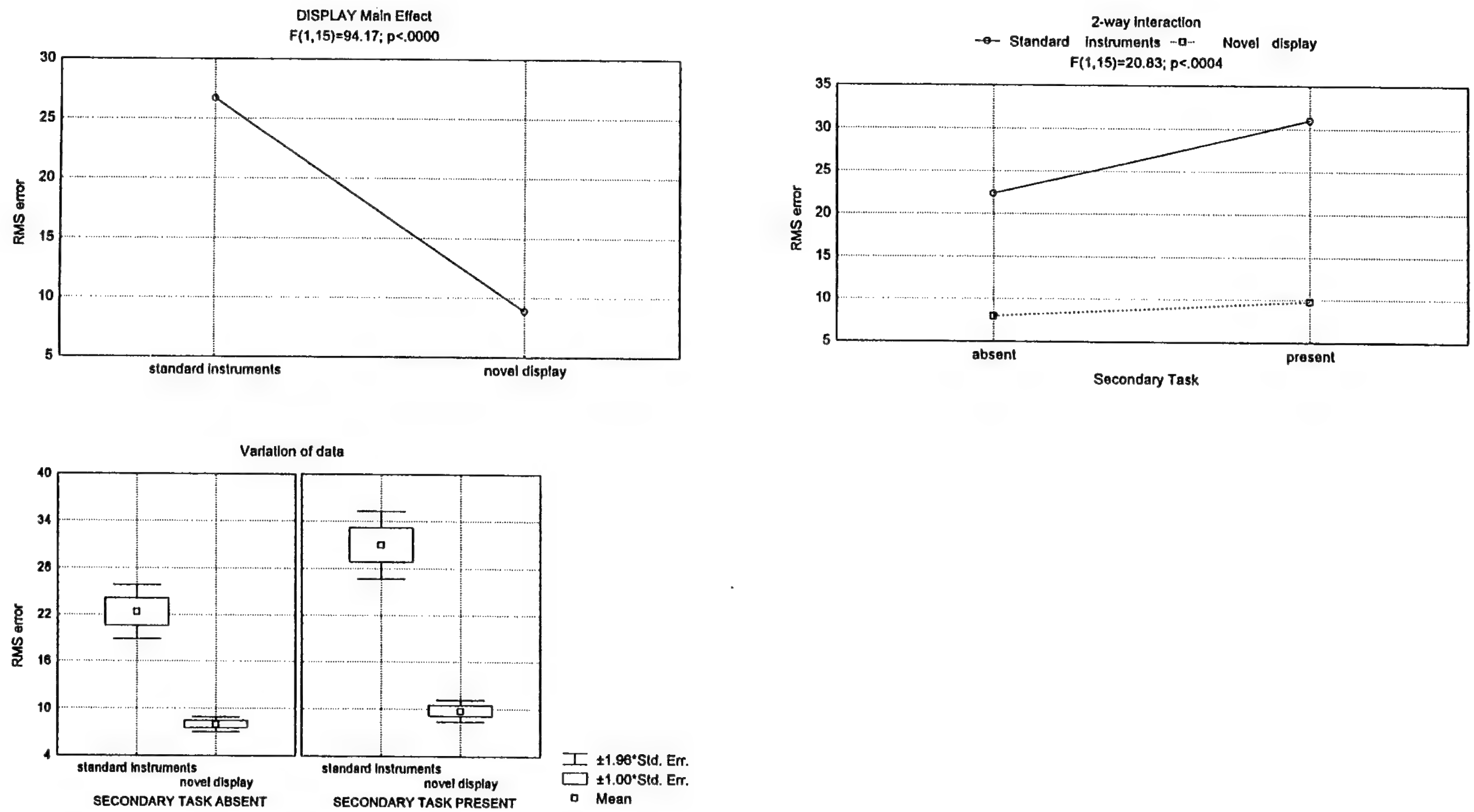


Figure 51. Parameter = altitude for all maneuvers (less climbs and descents), AFCS ON and OFF.

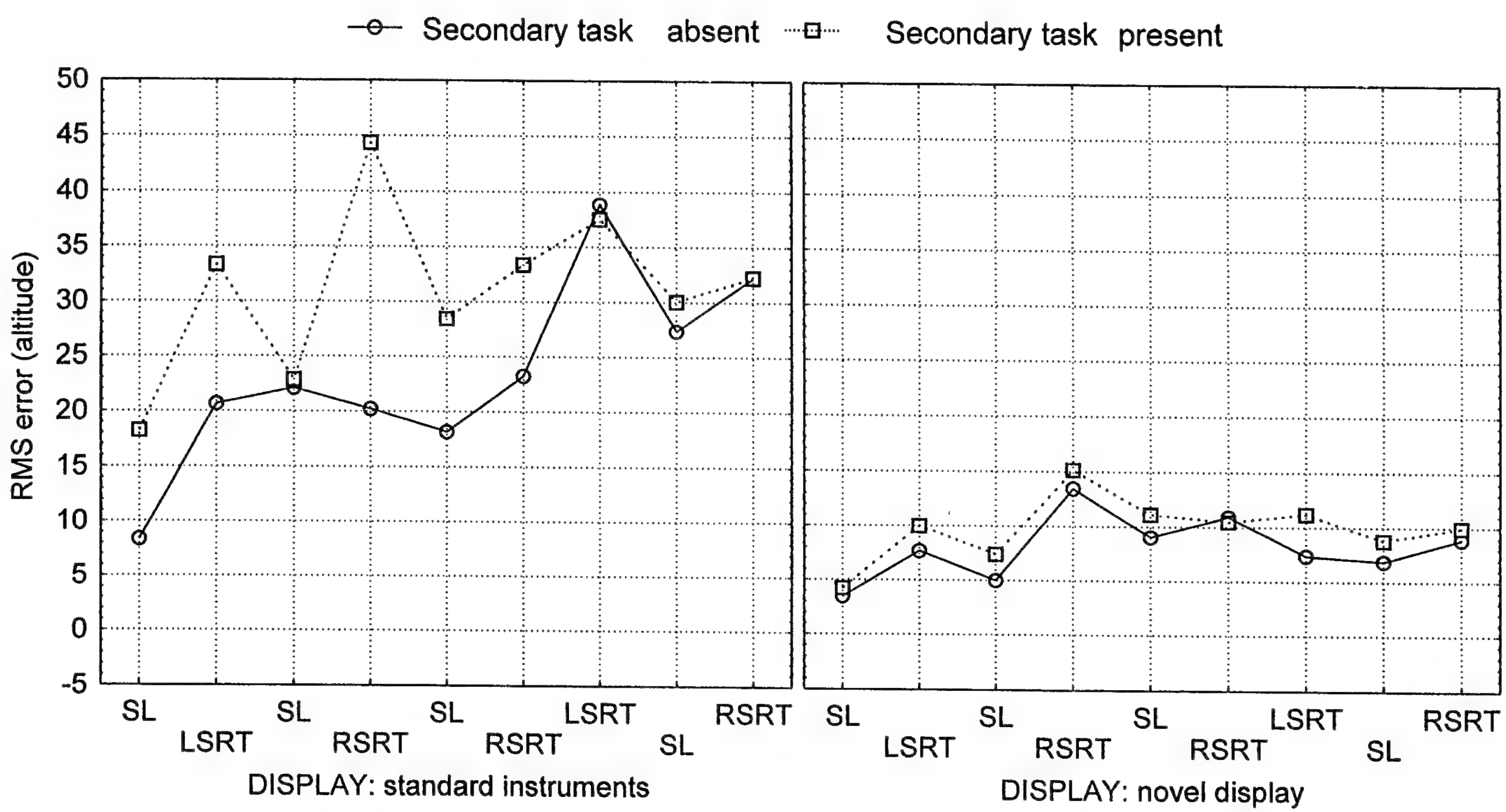


Figure 52. RMS error of altitude for level maneuvers by display type.

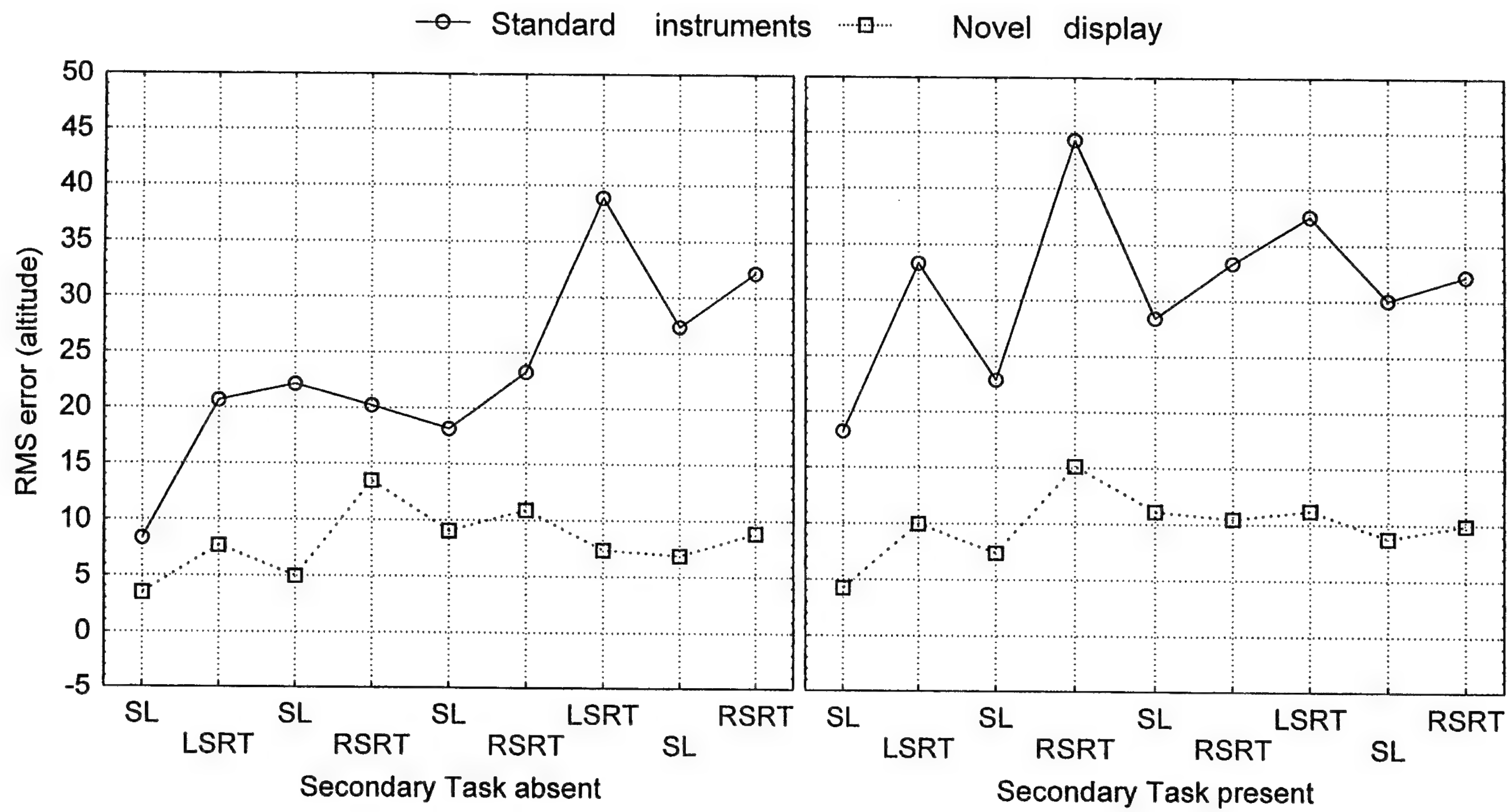


Figure 53. RMS error of altitude for level maneuvers by secondary task.

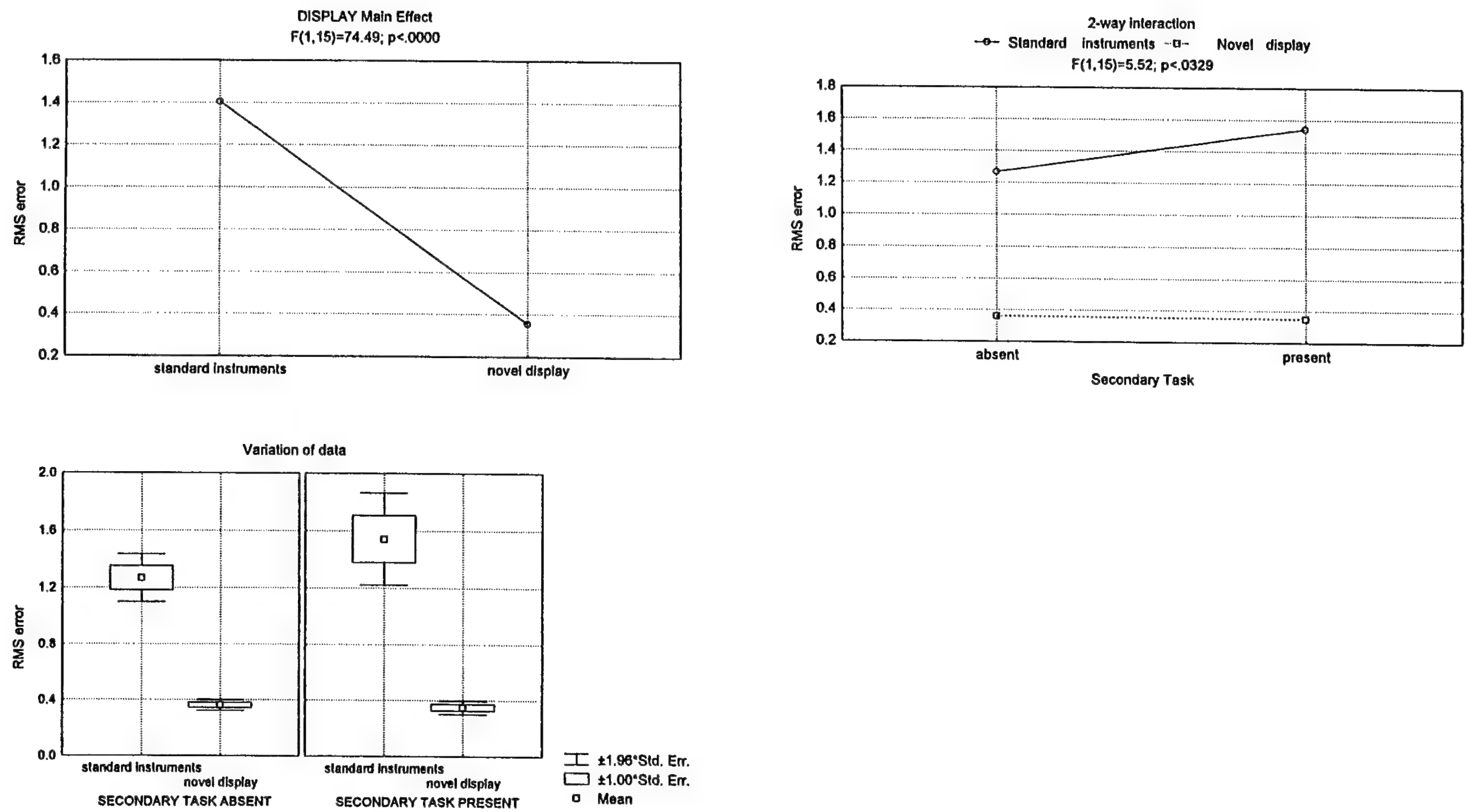


Figure 54. Parameter = heading for all maneuvers (less turns), AFCS ON.

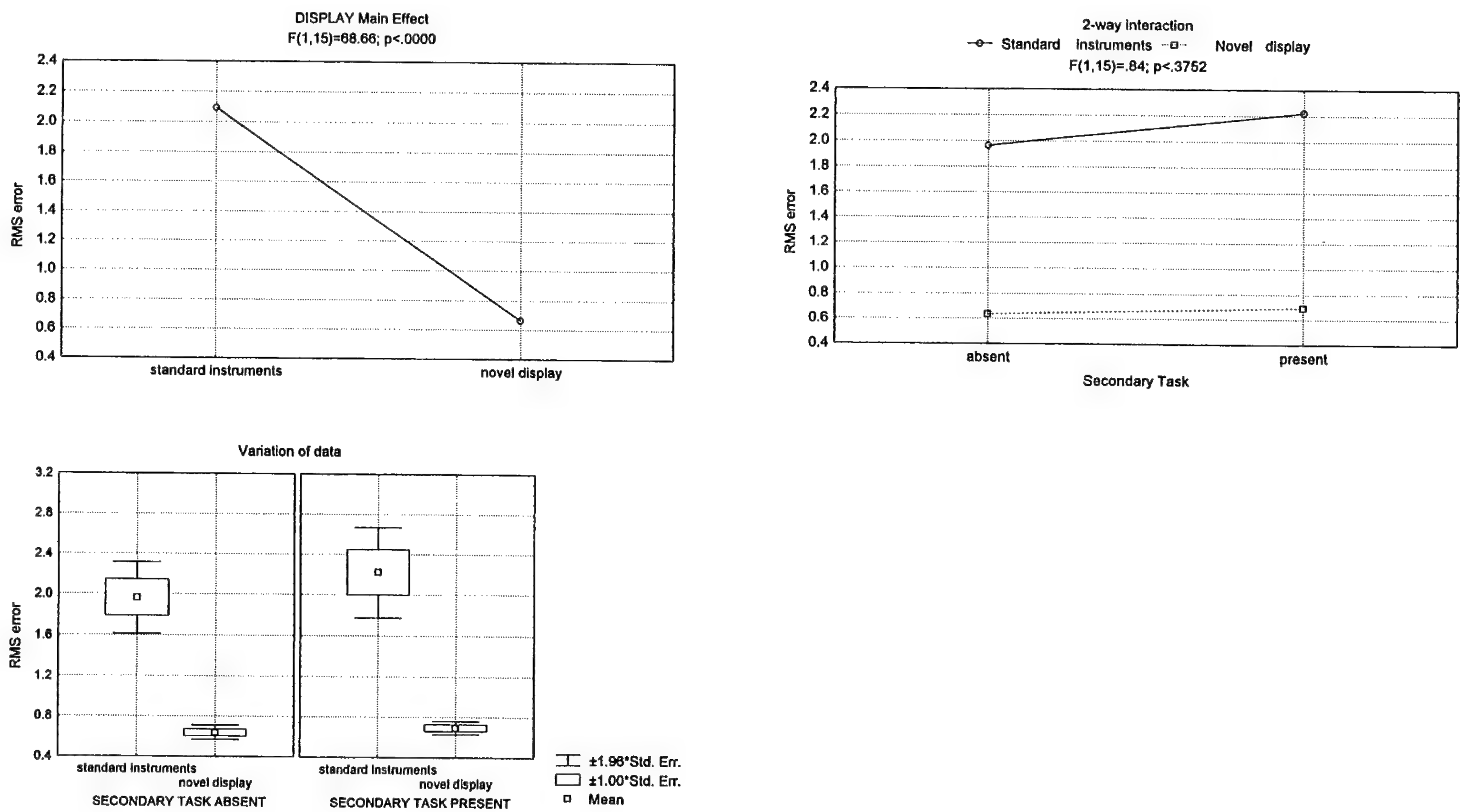


Figure 55. Parameter = heading for all maneuvers (less turns), AFCS OFF.

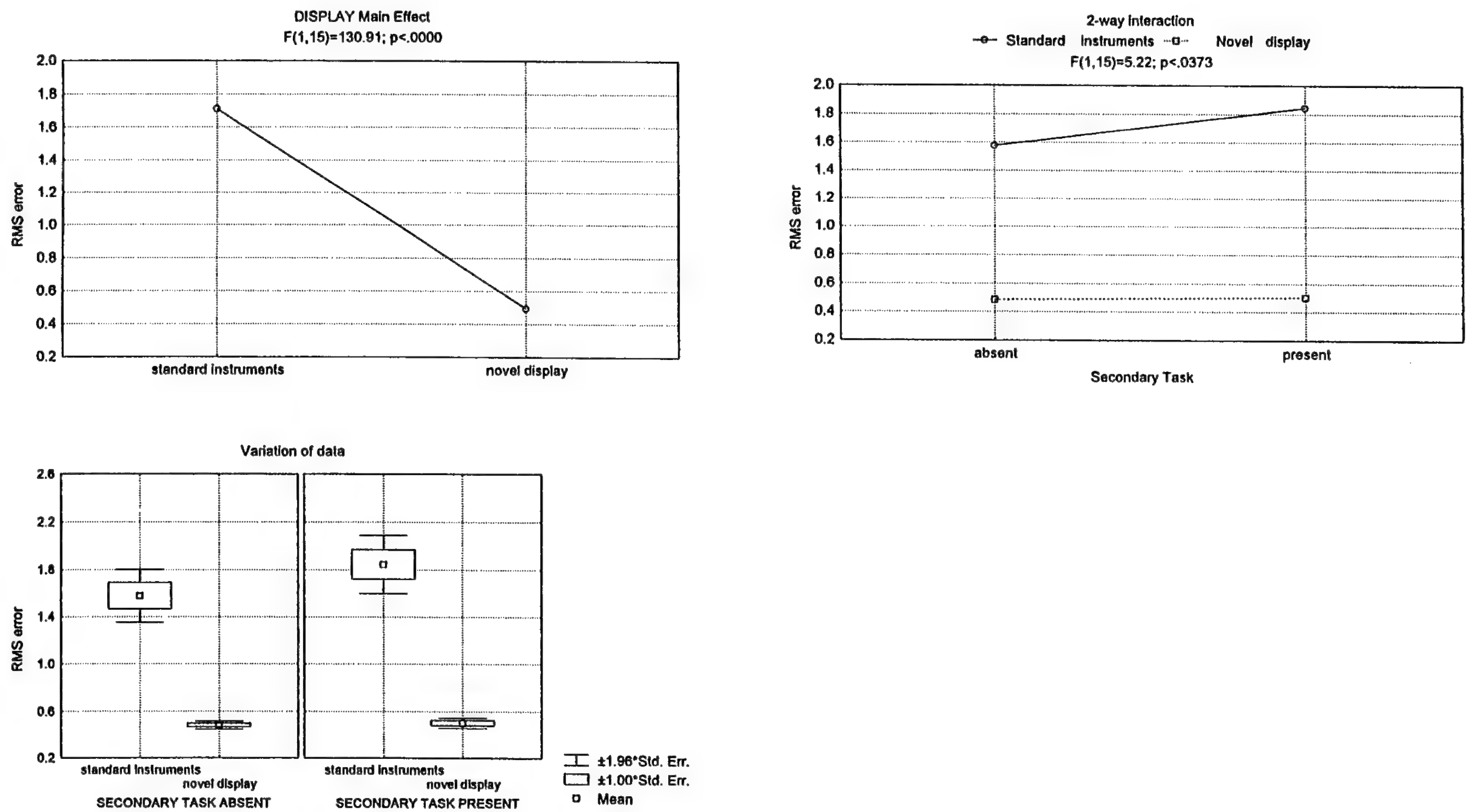


Figure 56. Parameter = heading for all maneuvers (less turns), AFCS ON and OFF.

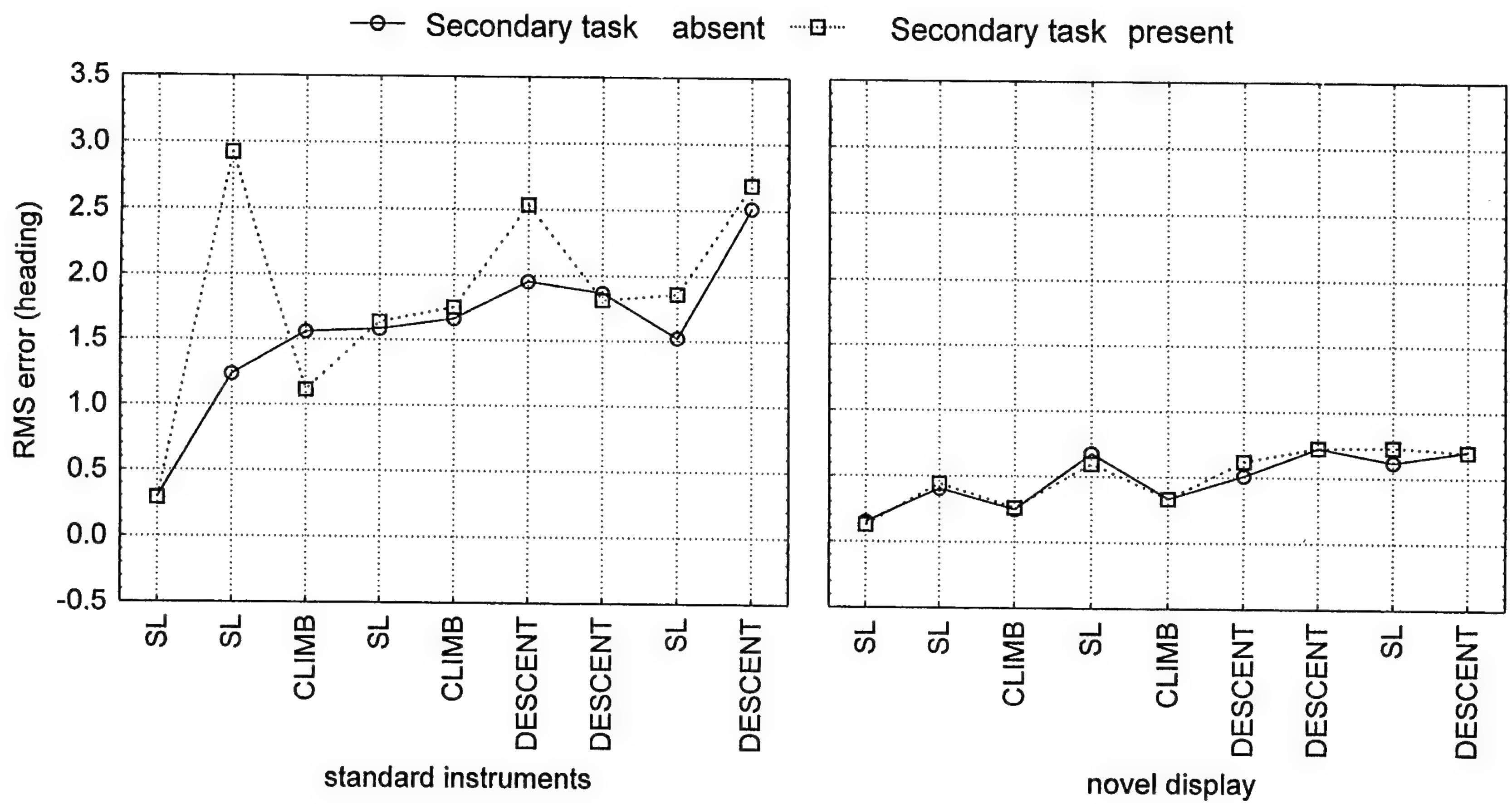


Figure 57. RMS error of heading for all maneuvers (less turns) by display type.

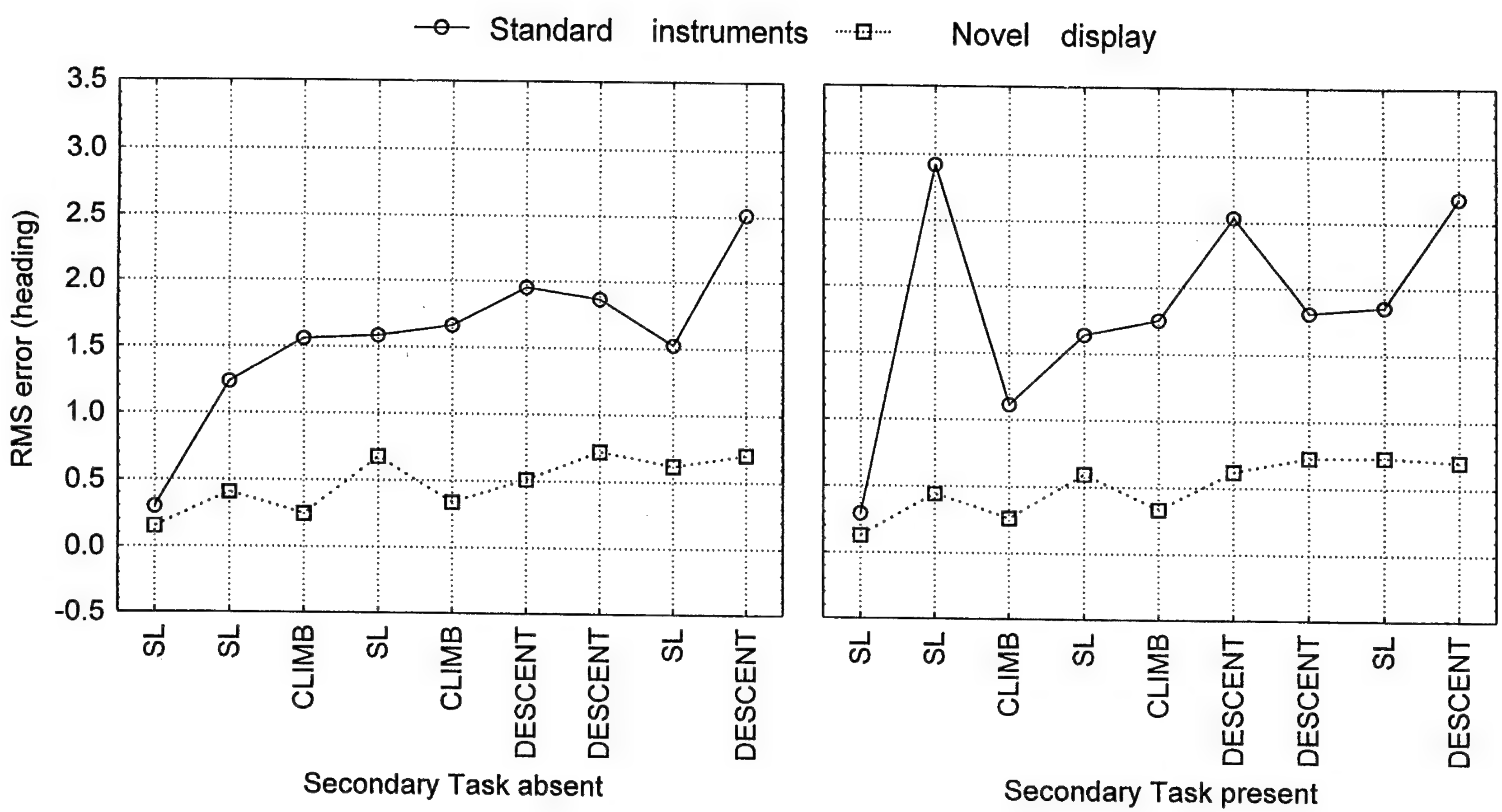


Figure 58. RMS error of heading for all maneuvers (less turns) by secondary task.

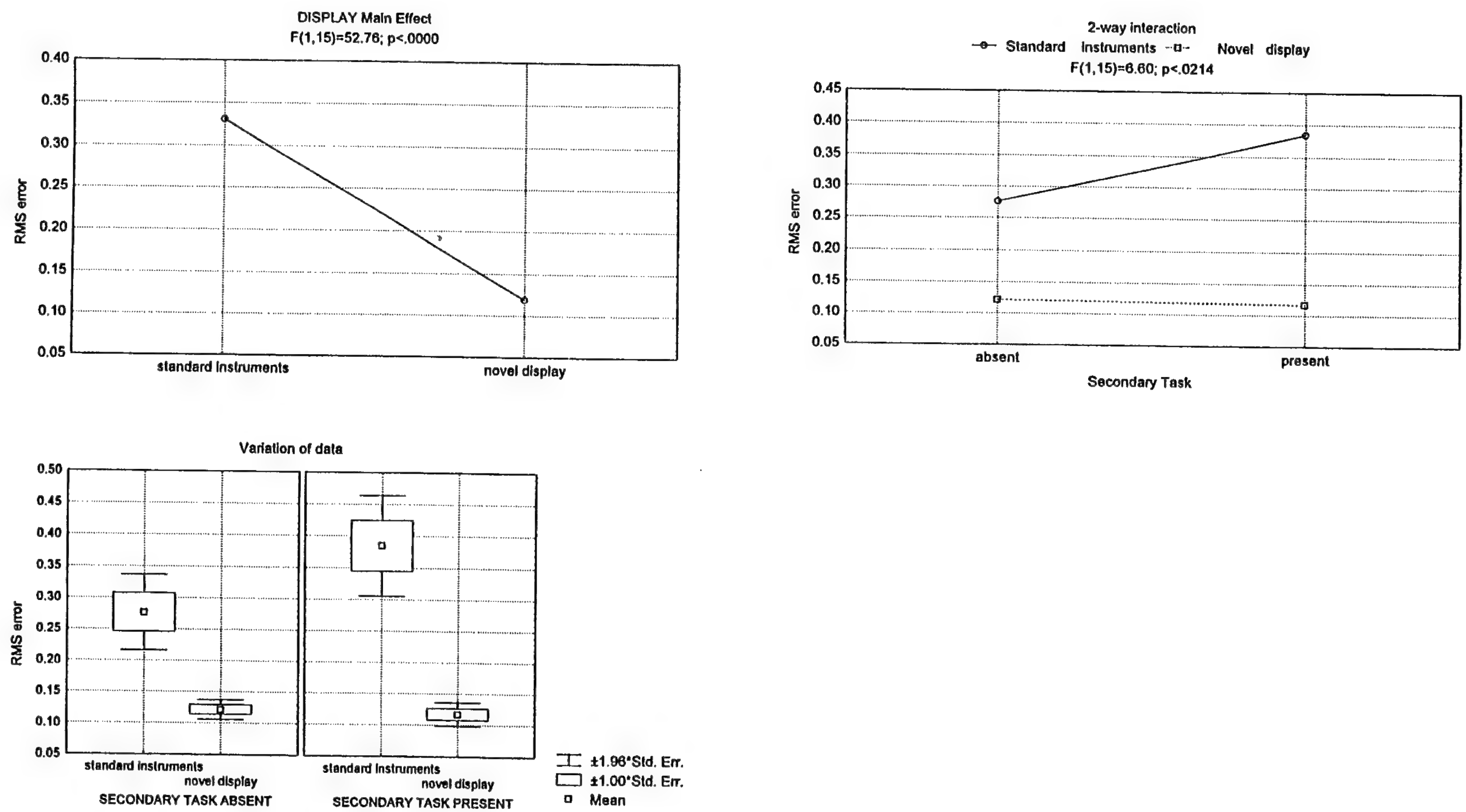


Figure 59. Parameter = turn rate for all turns, AFCS ON.

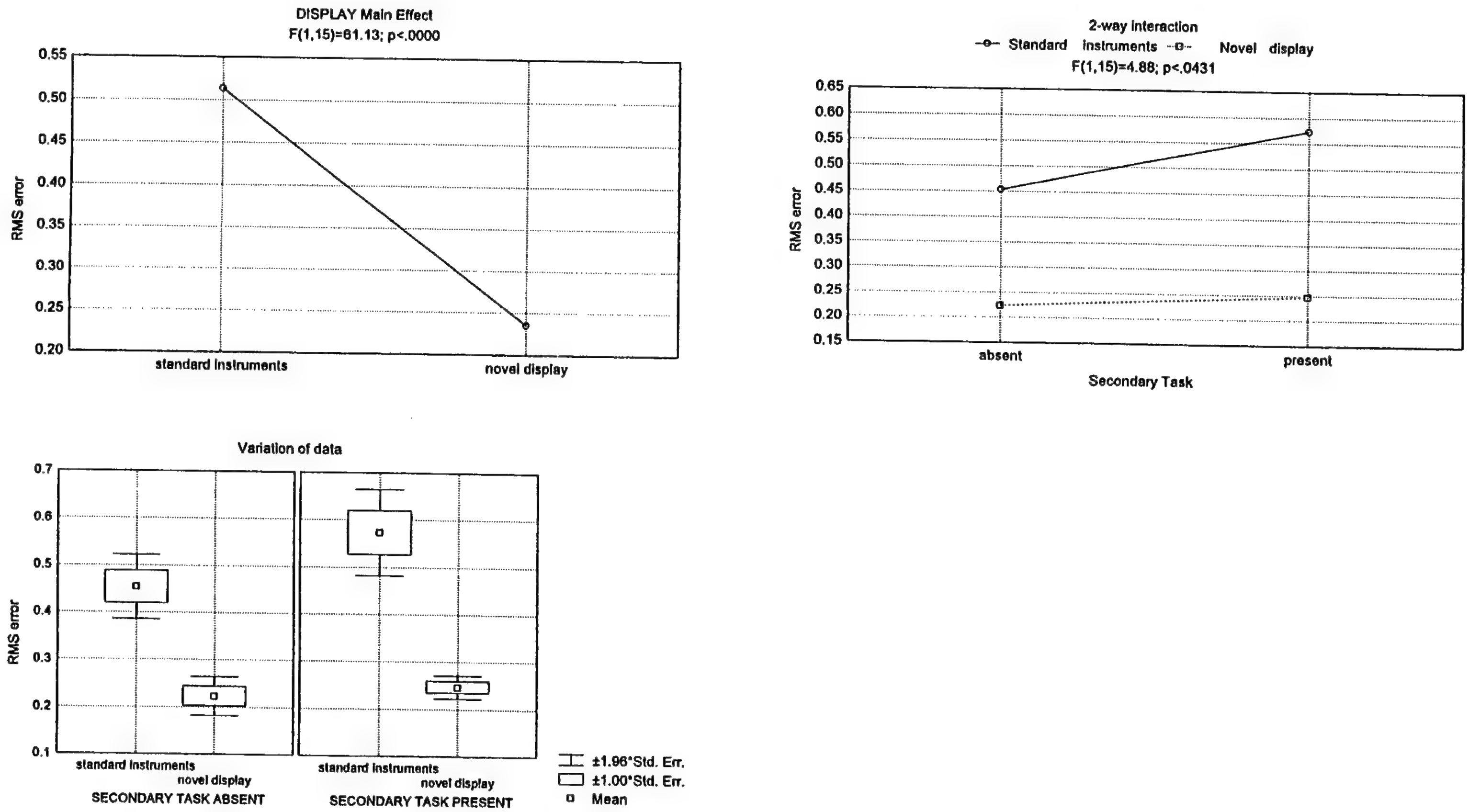


Figure 60. Parameter = turn rate for all turns, AFCS OFF.

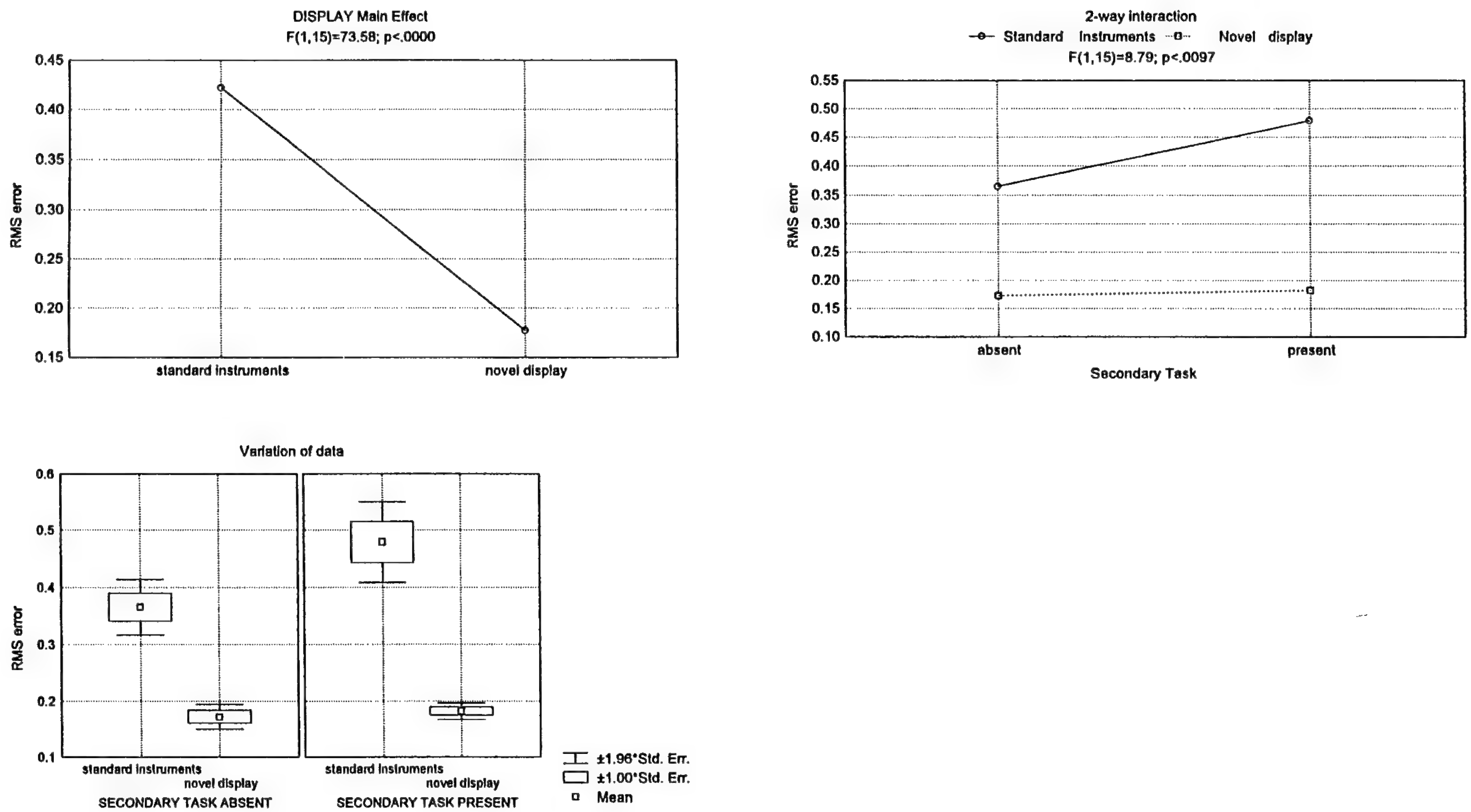


Figure 61. Parameter = turn rate for all turns, AFCS ON and OFF.

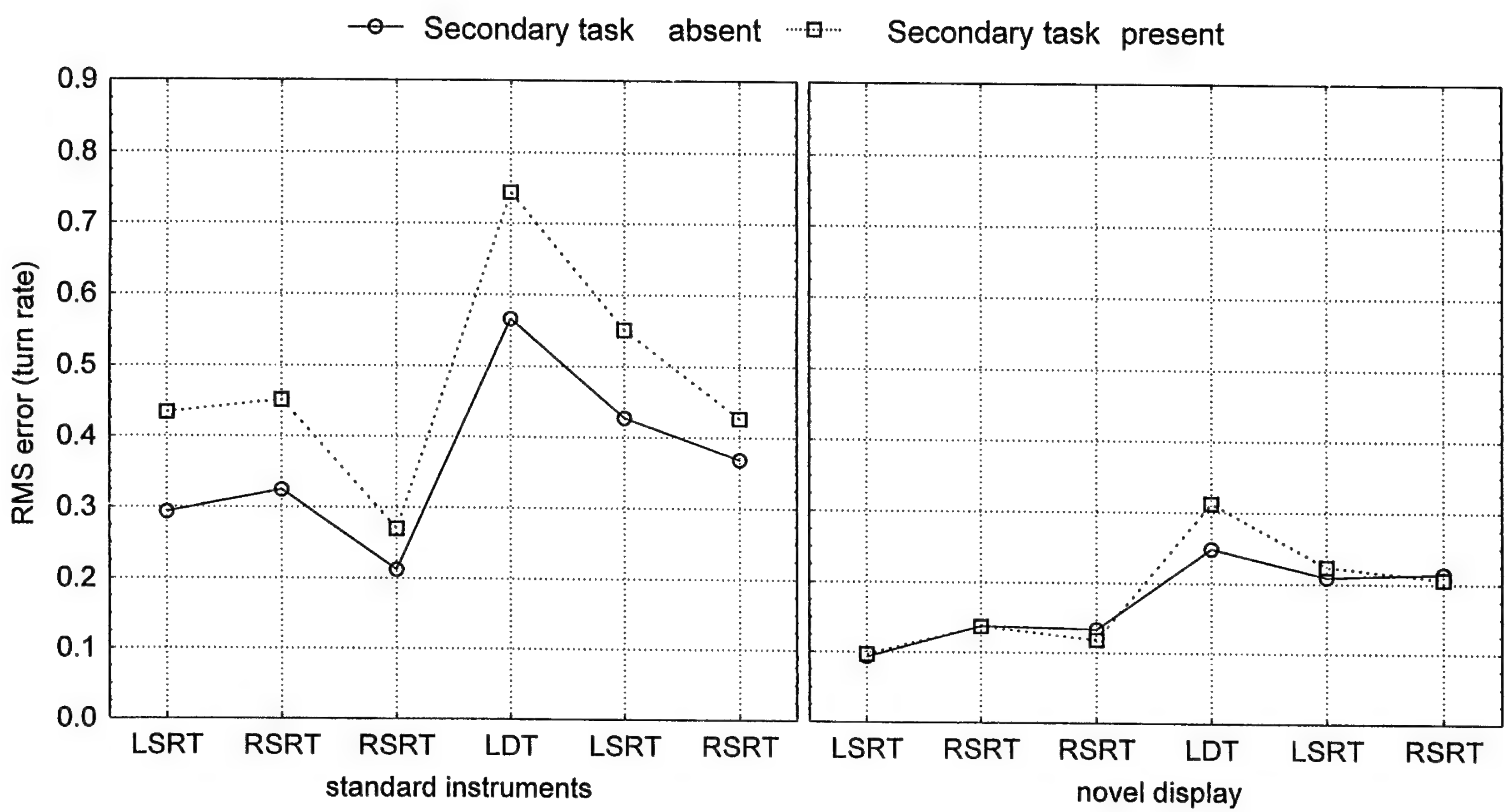


Figure 62. RMS error of turn rate for all turns by display type.

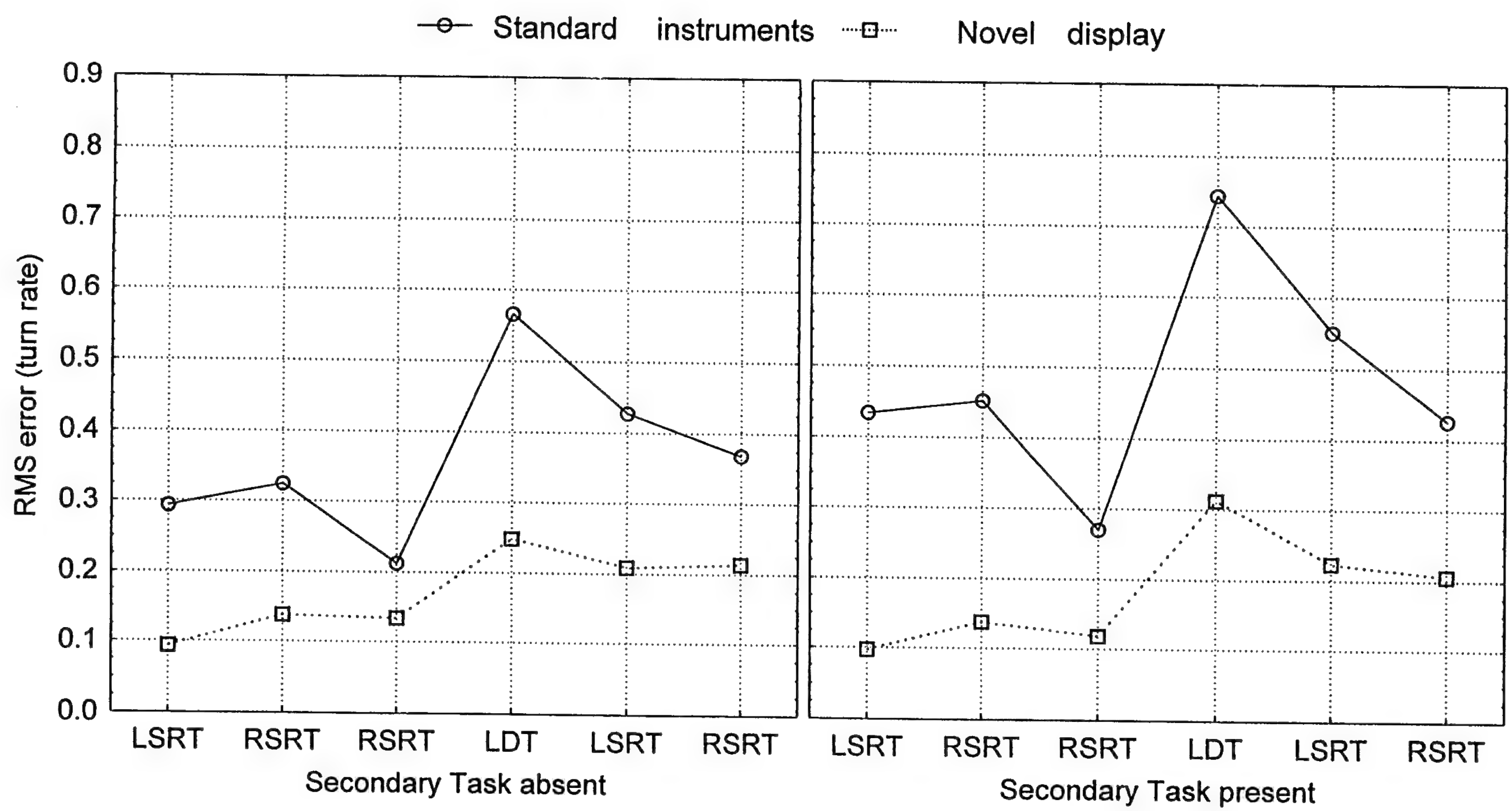


Figure 63. RMS error of turn rate for all turns by secondary task.

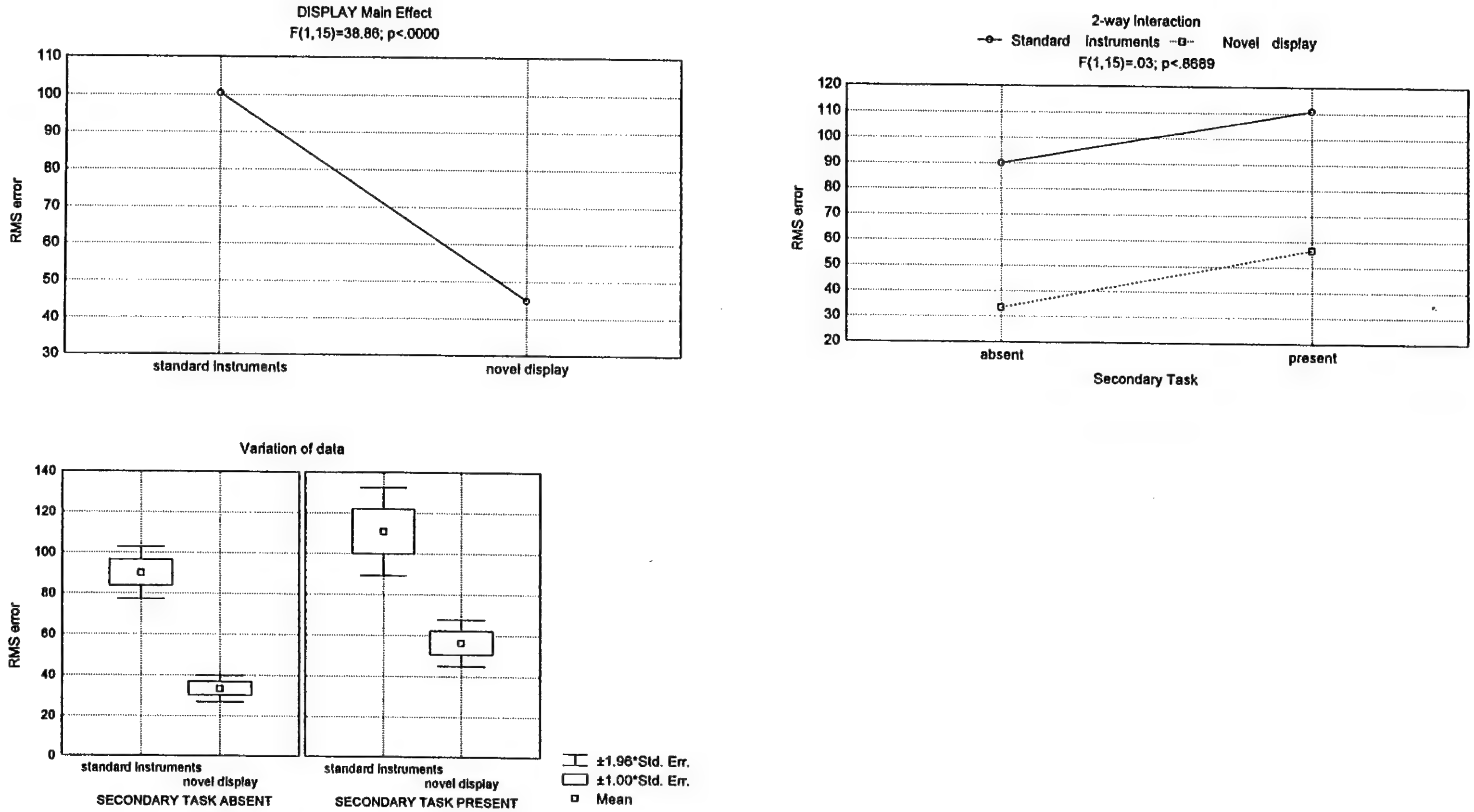


Figure 64. Parameter = vertical speed for all climbs, AFCS ON.

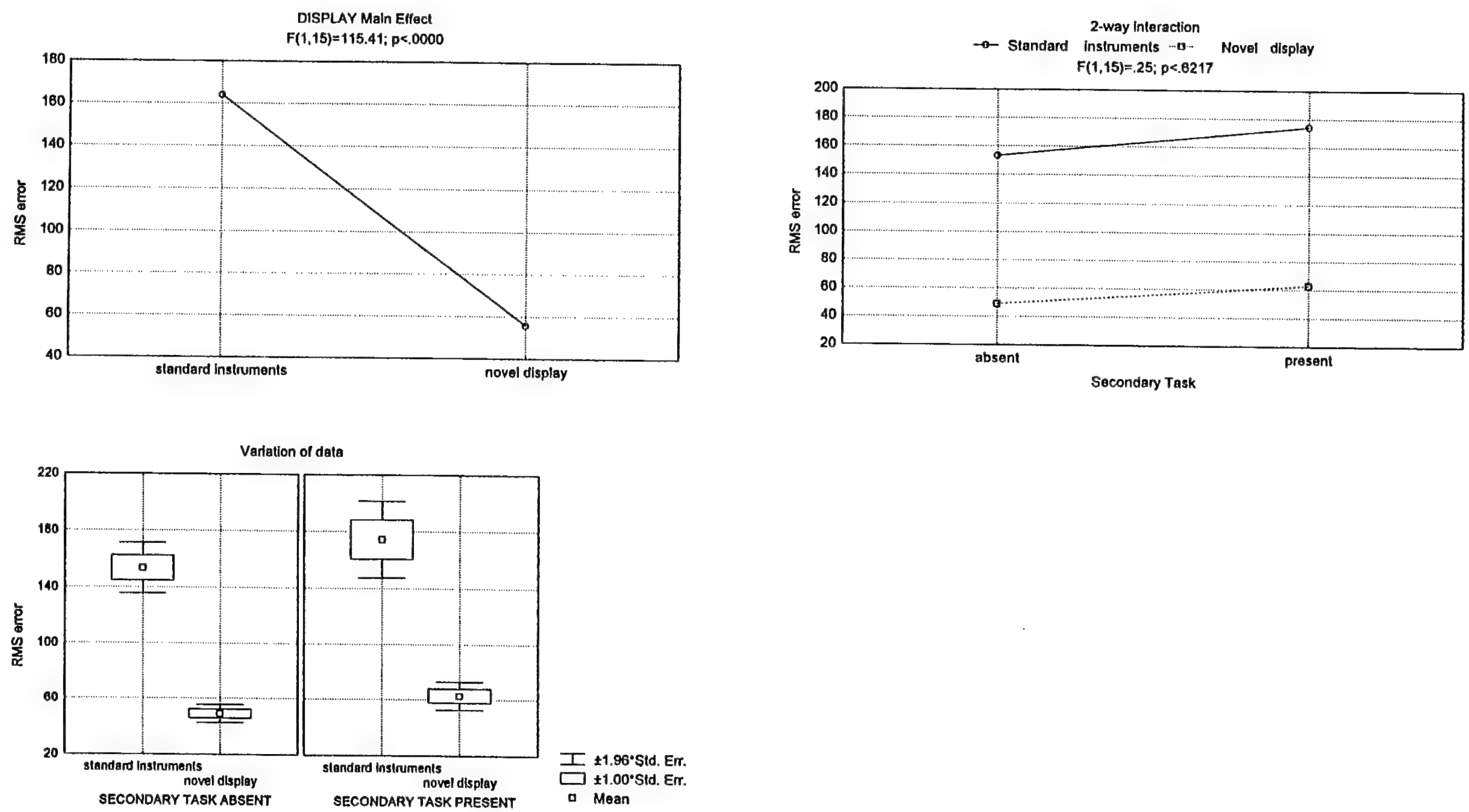


Figure 65. Parameter = vertical speed for all descents, AFCS OFF.

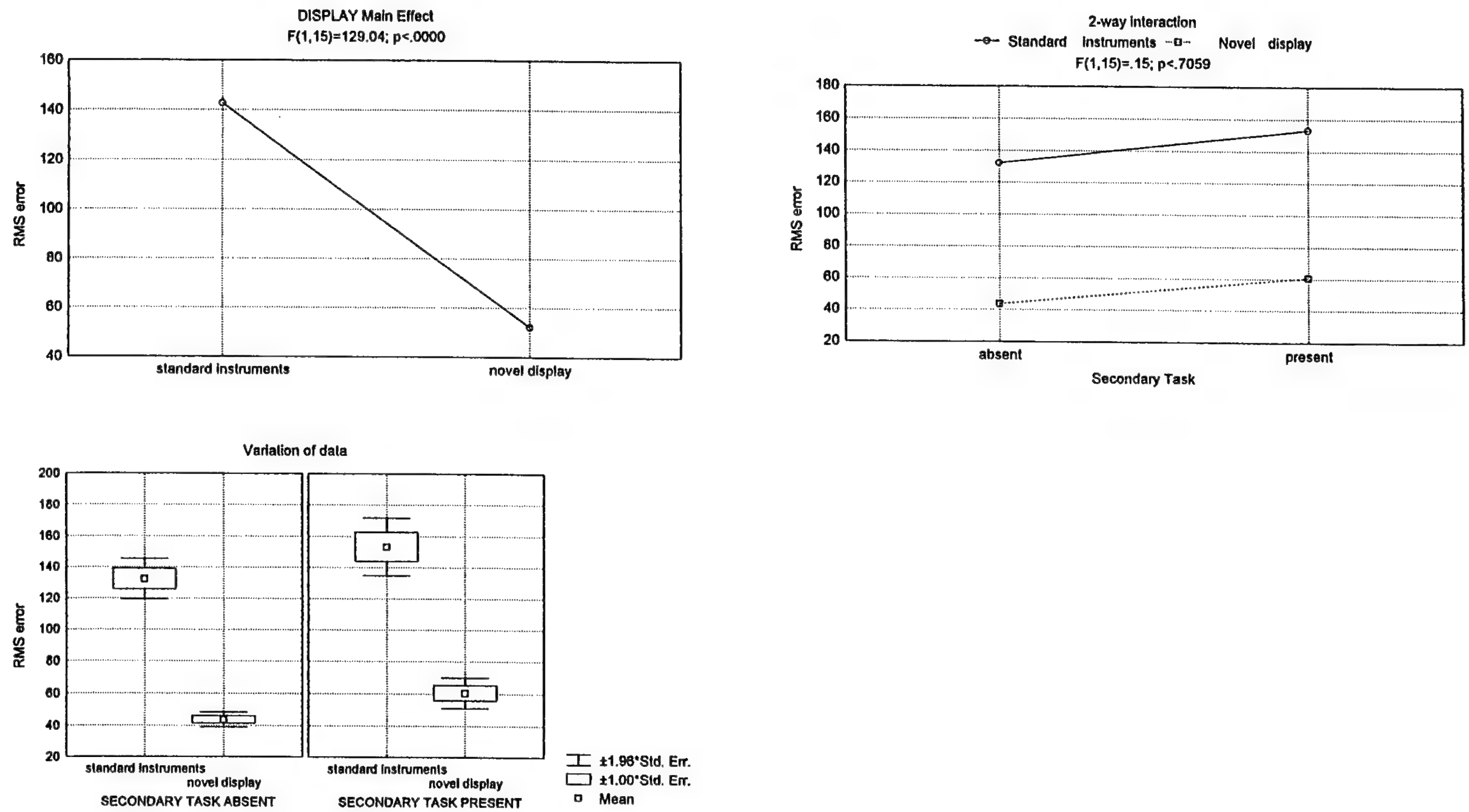


Figure 66. Parameter = vertical speed for all climbs and descents, AFCS ON and OFF.

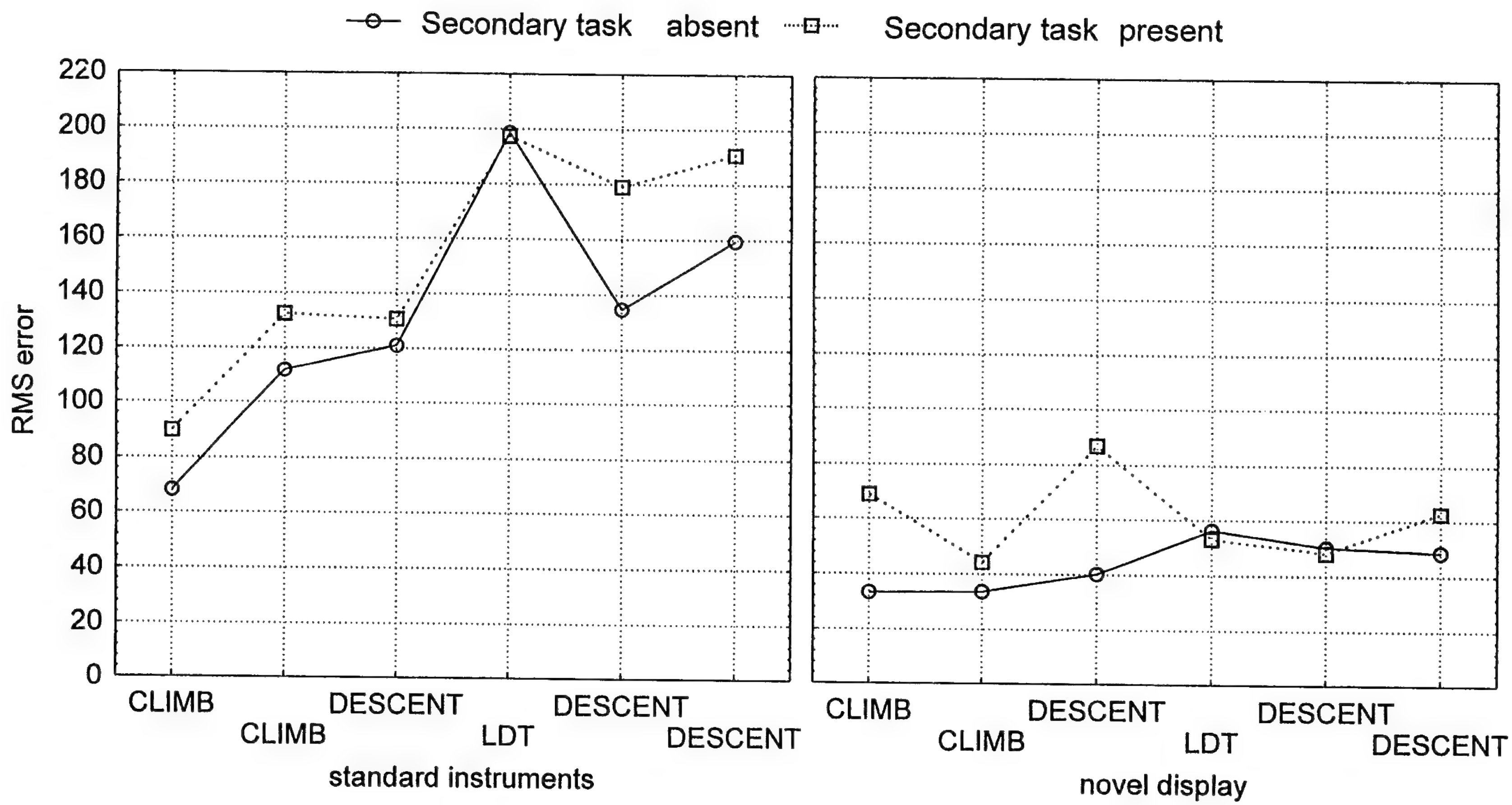


Figure 67. RMS error of vertical speed for all climbs and descents by display.

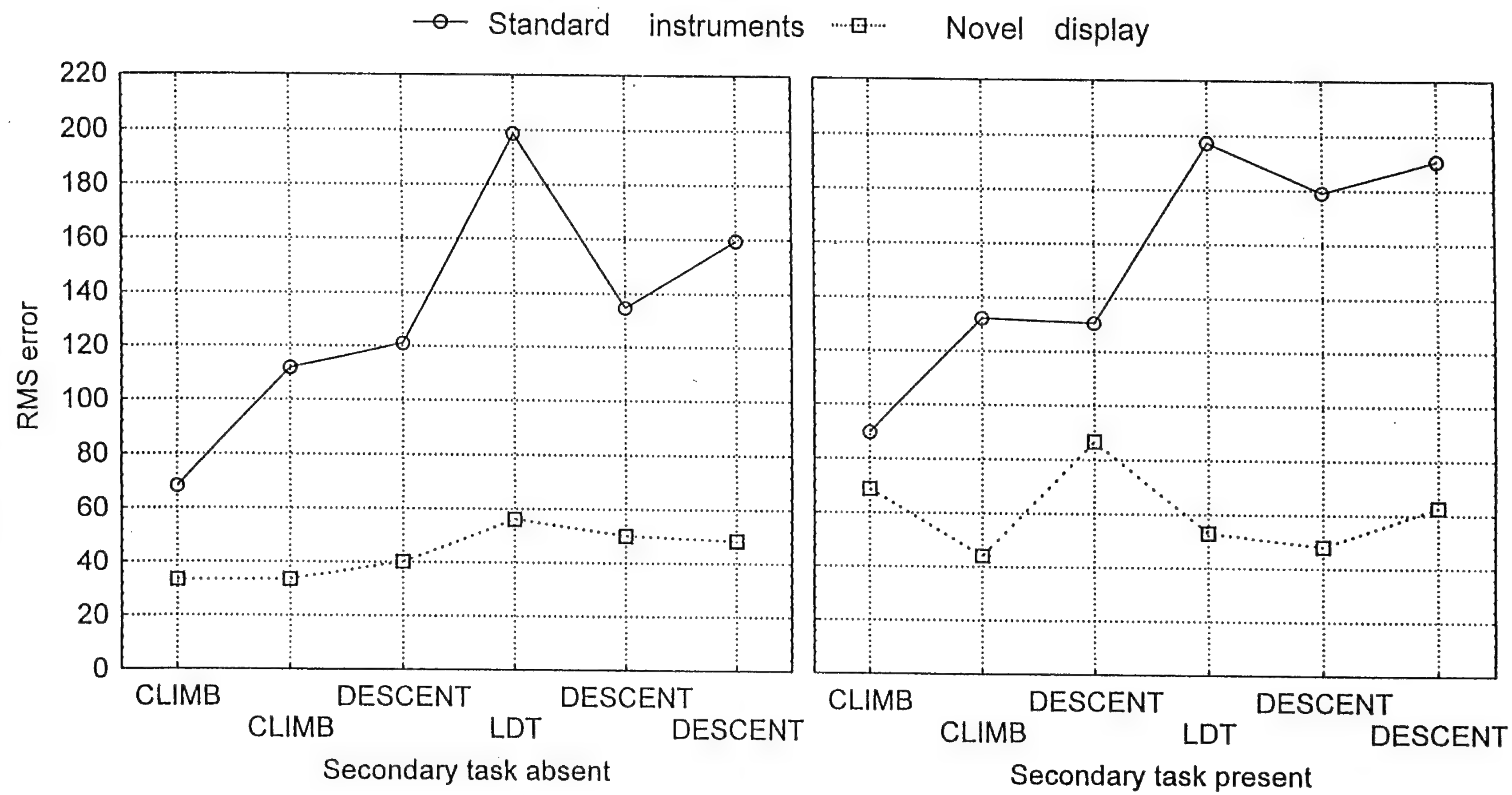


Figure 68. RMS error of vertical speed for all climbs and descents by secondary task.

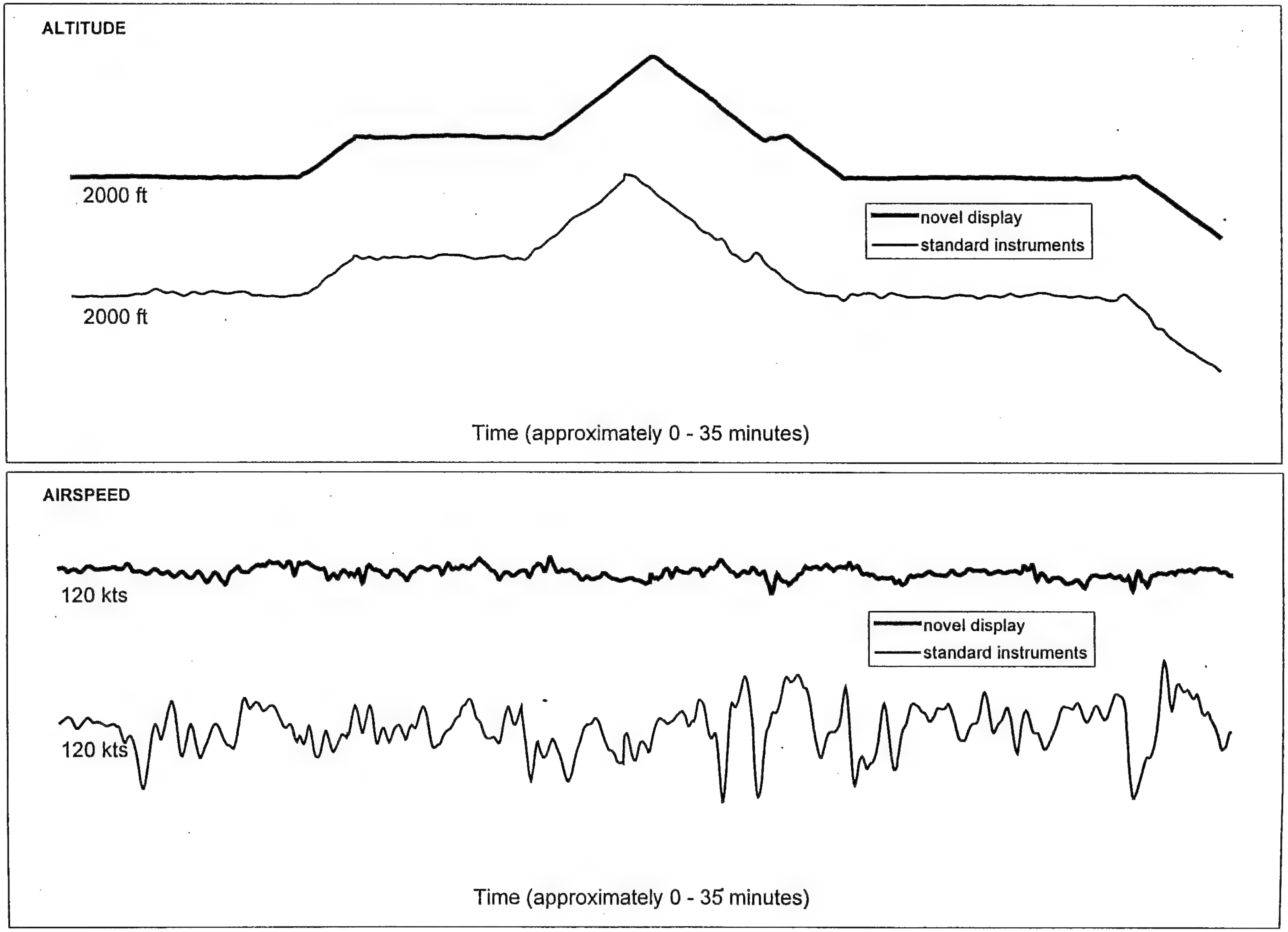


Figure 69. Subject 11 (experienced pilot) - Instrument flying profile with secondary task absent.

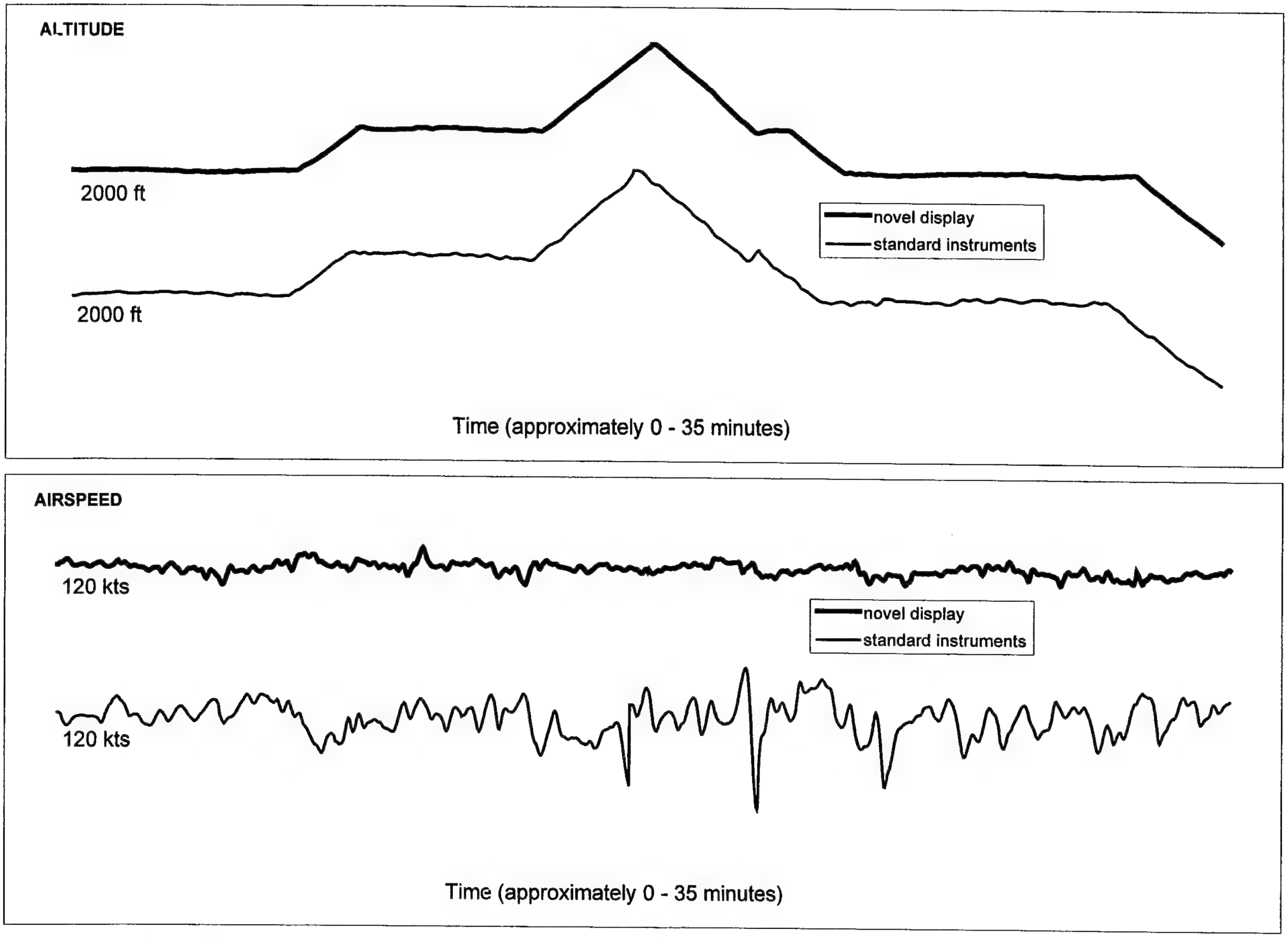


Figure 70. Subject 11 (experienced pilot) - Instrument flying profiles with secondary task present.

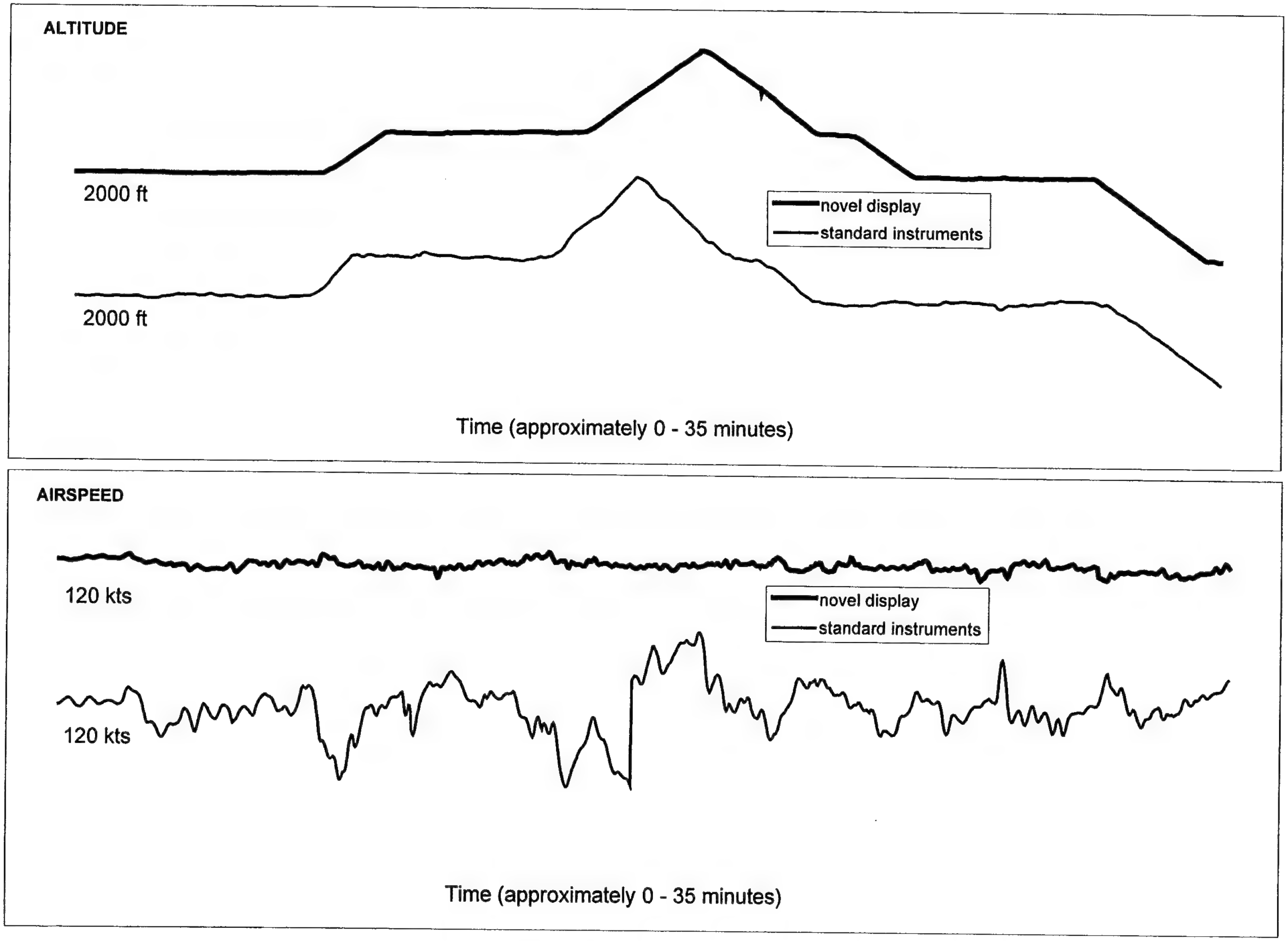


Figure 71. Subject 15 (novice pilot) - Instrument flying profiles with secondary task absent.

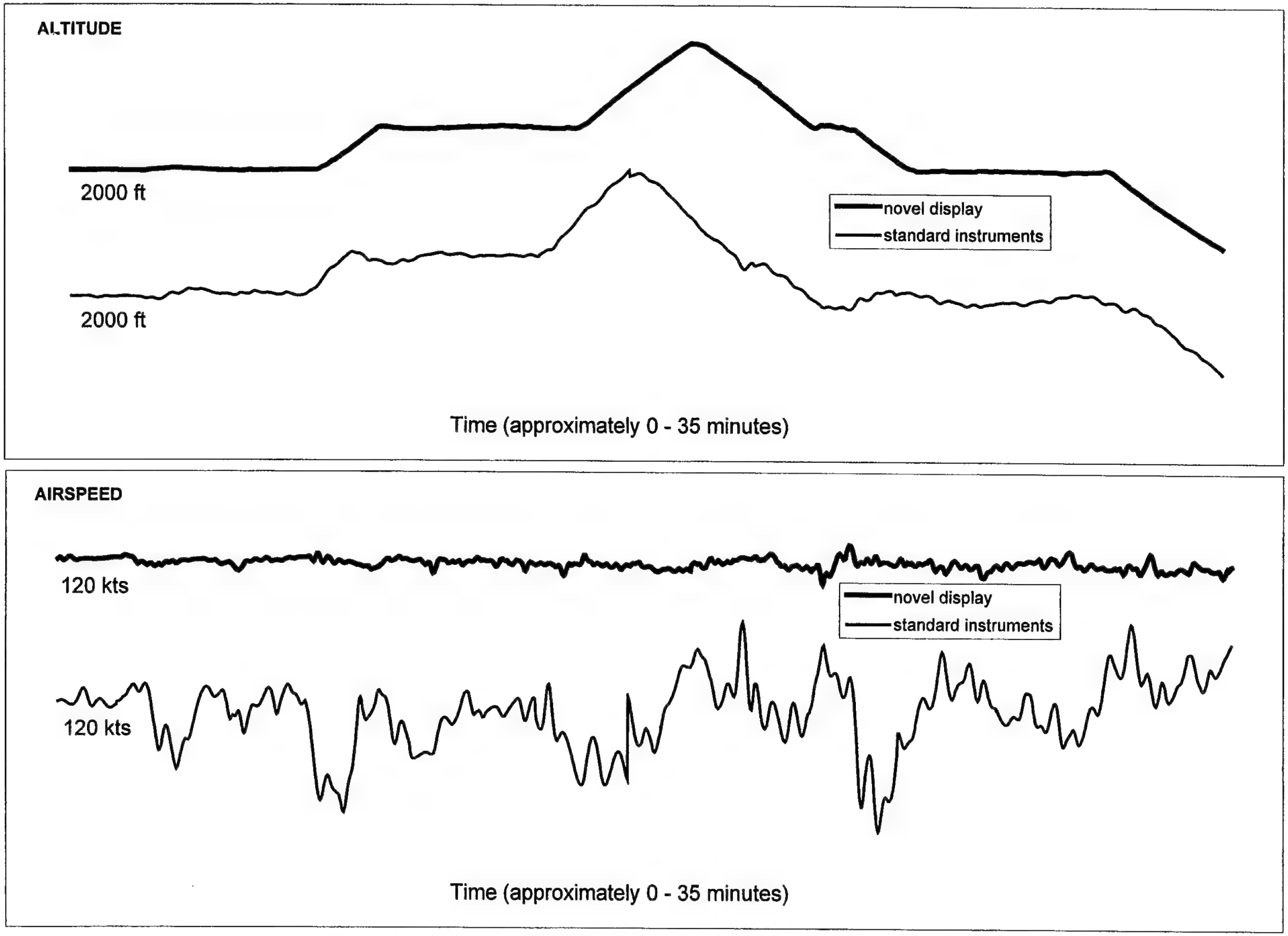


Figure 72. Subject 15 (novice pilot) - Instrument flying profiles with secondary task present.

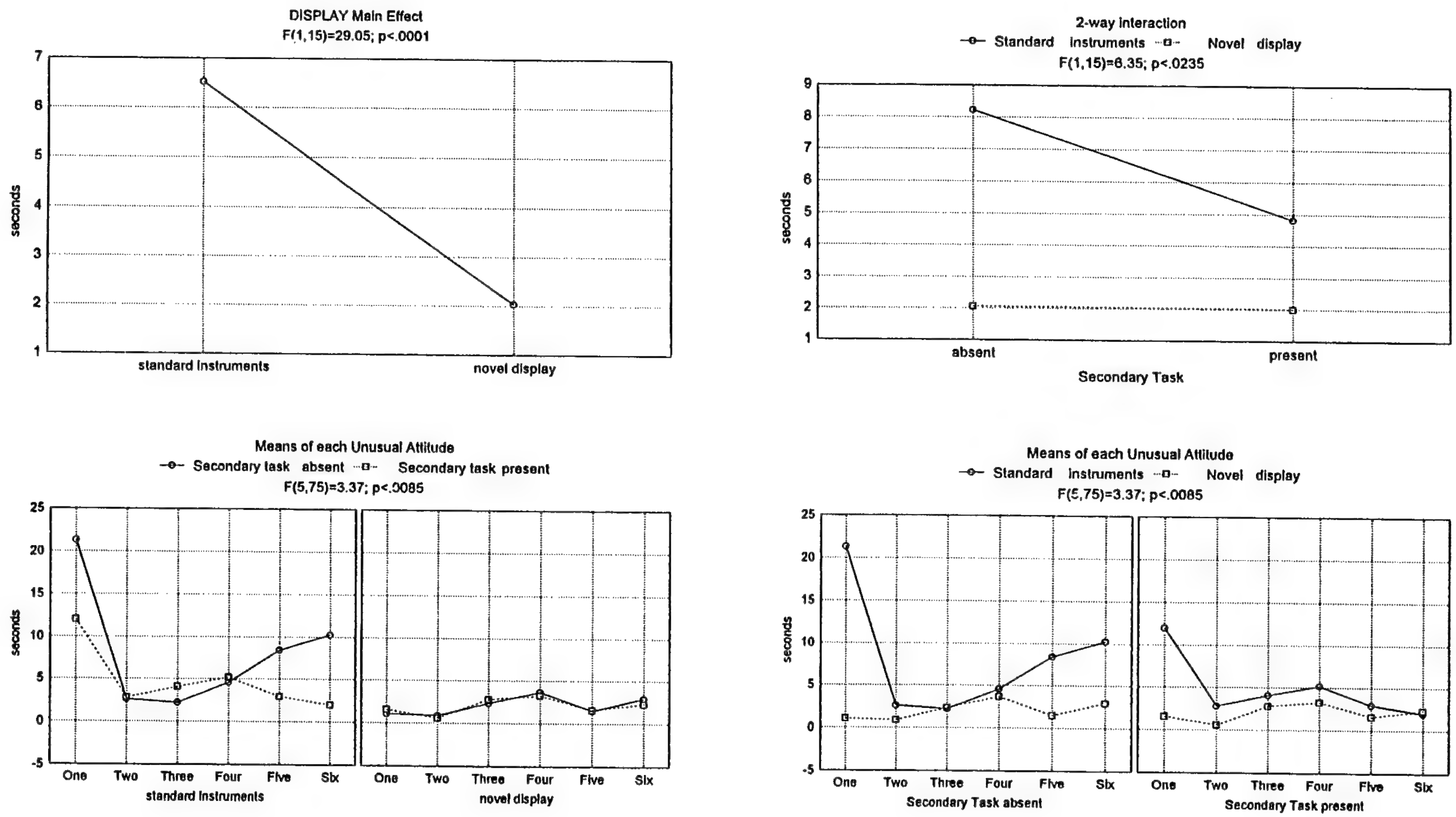


Figure 73. Unusual attitudes - time to wings level.

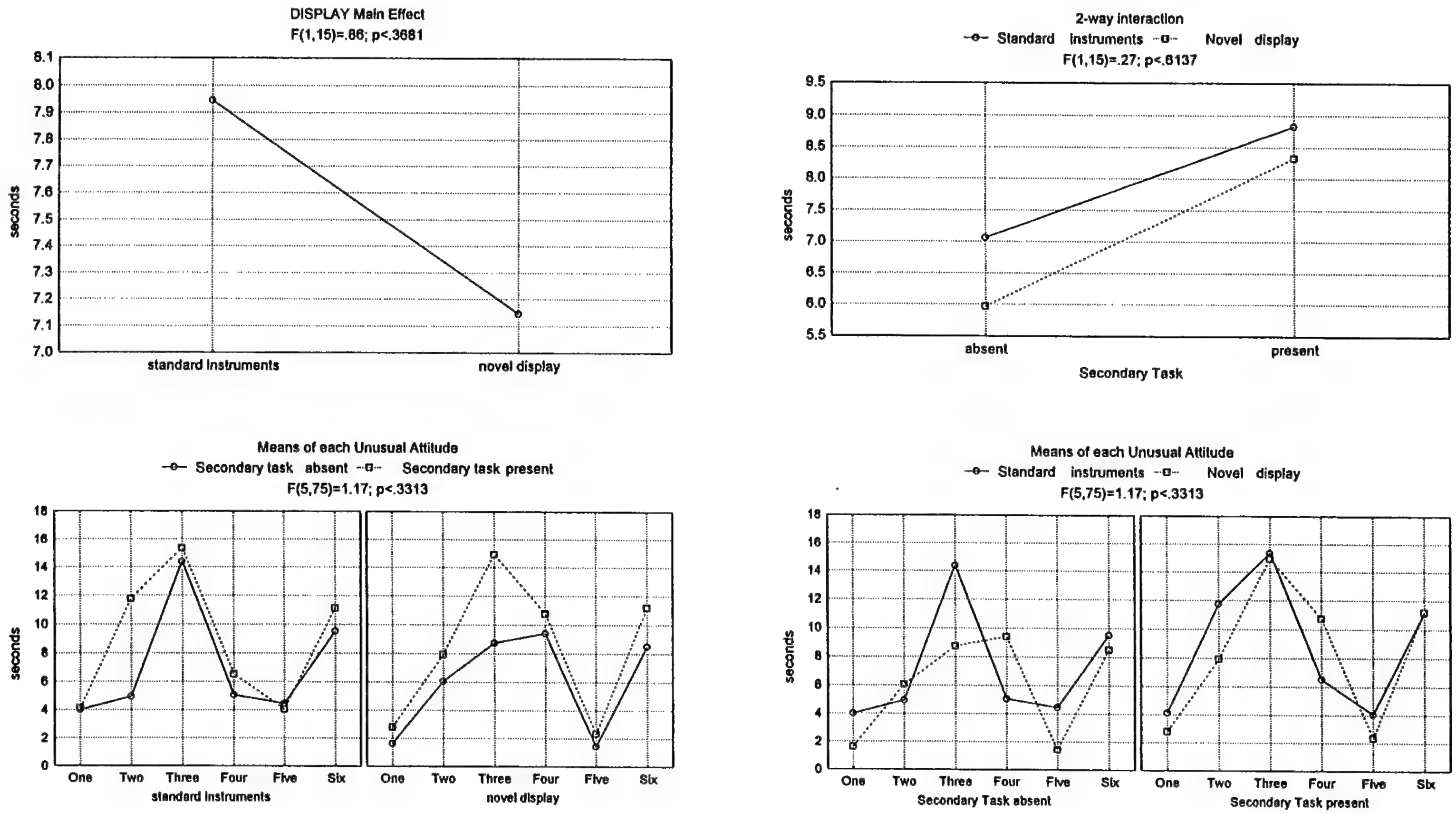


Figure 74. Unusual attitudes - time to pitch level appropriate to airspeed.

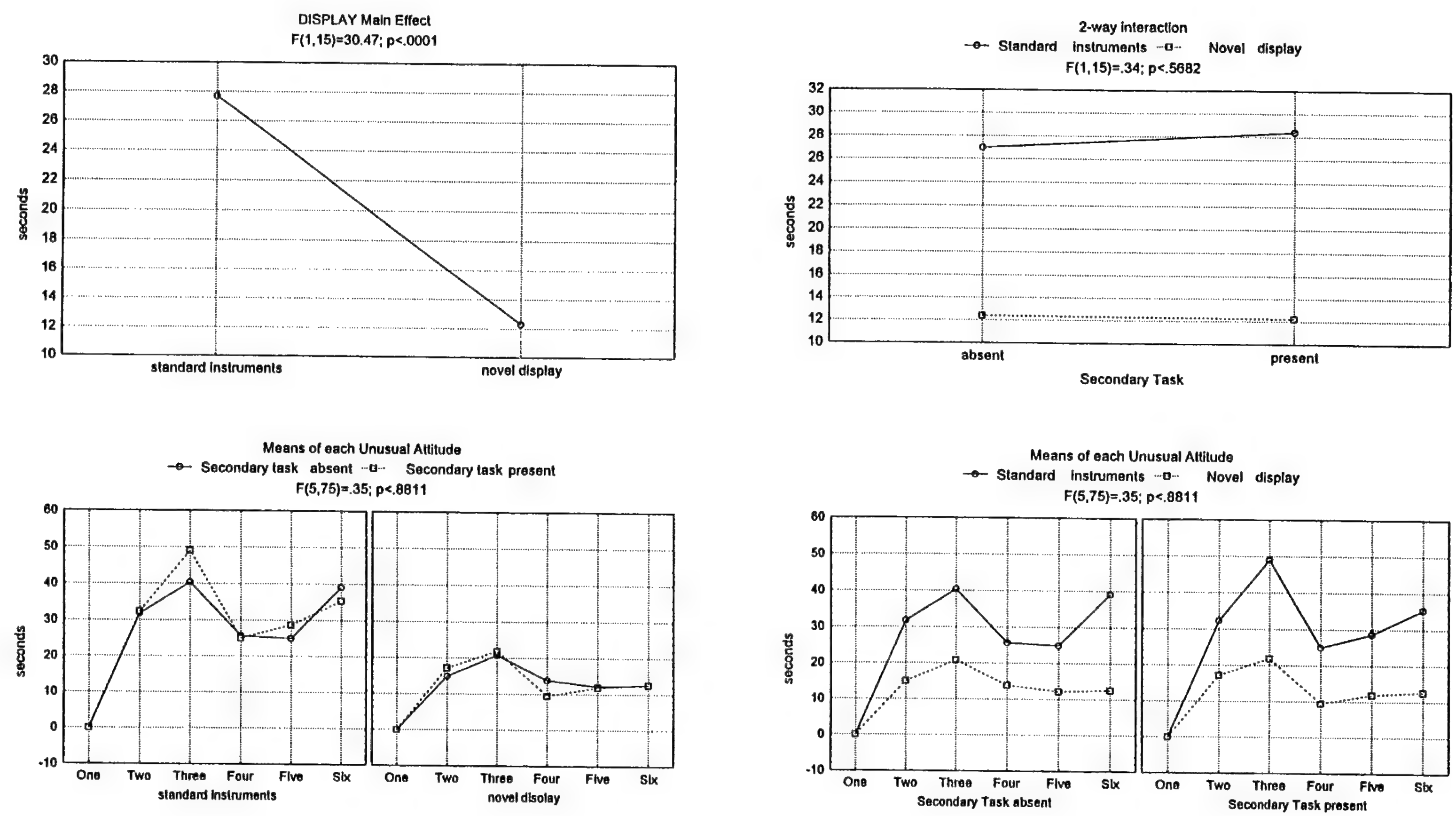


Figure 75. Unusual attitudes - time to desired airspeed (+/- 10 kts).

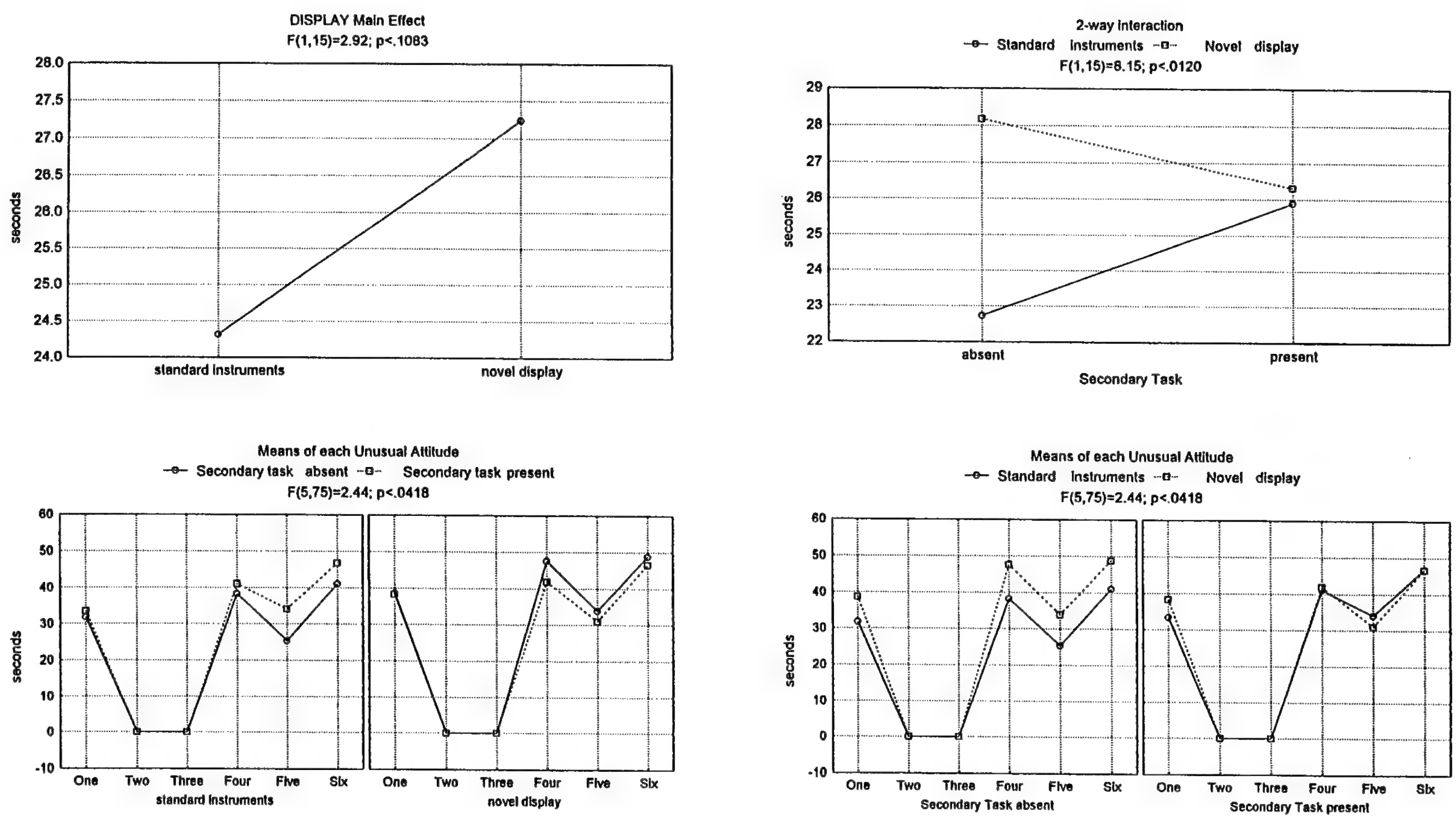


Figure 76. Unusual attitudes - time to desired heading (+/- 10 degrees).

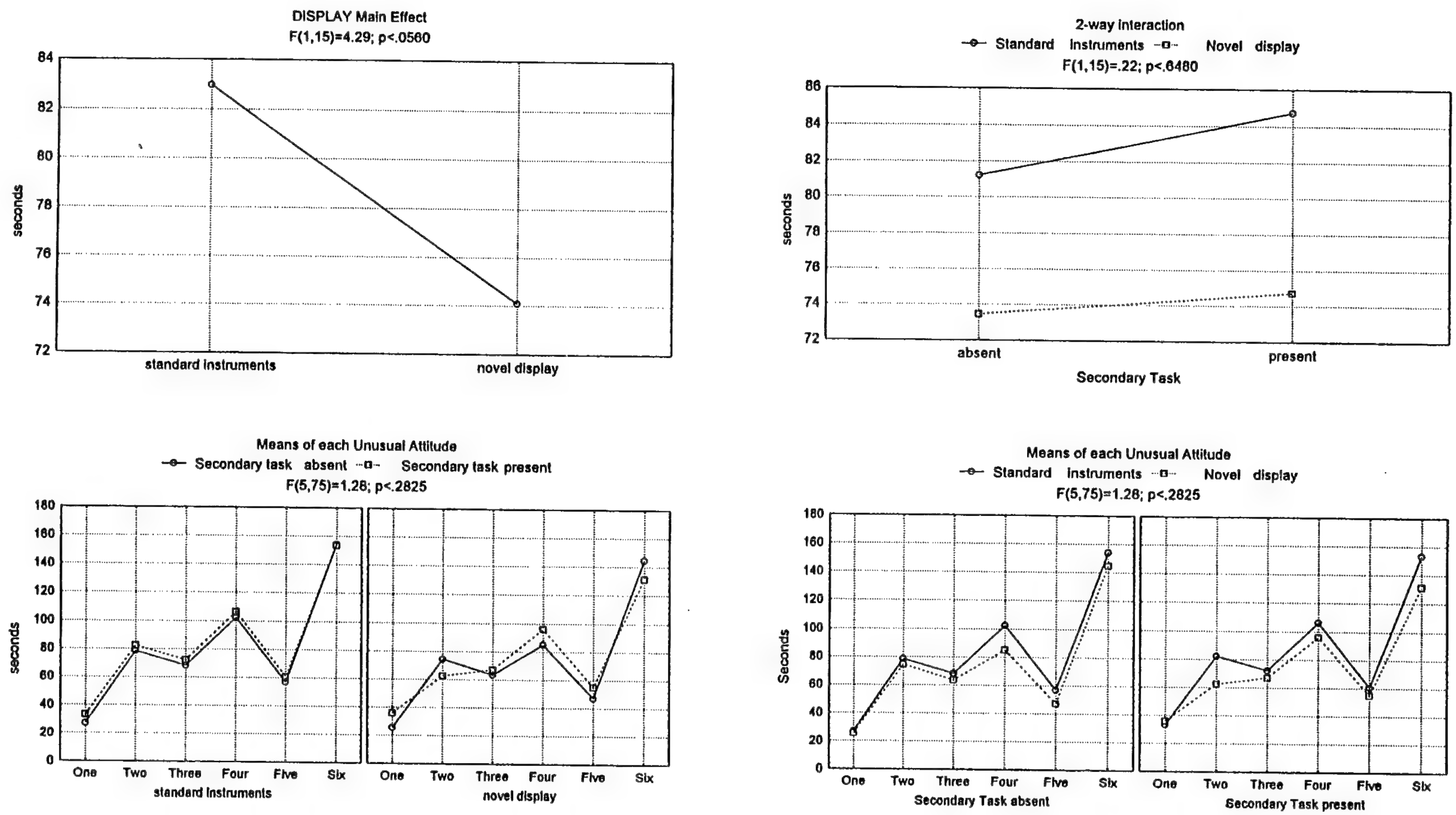


Figure 77. Unusual attitudes - time to desired altitude (+/- 100 ft).

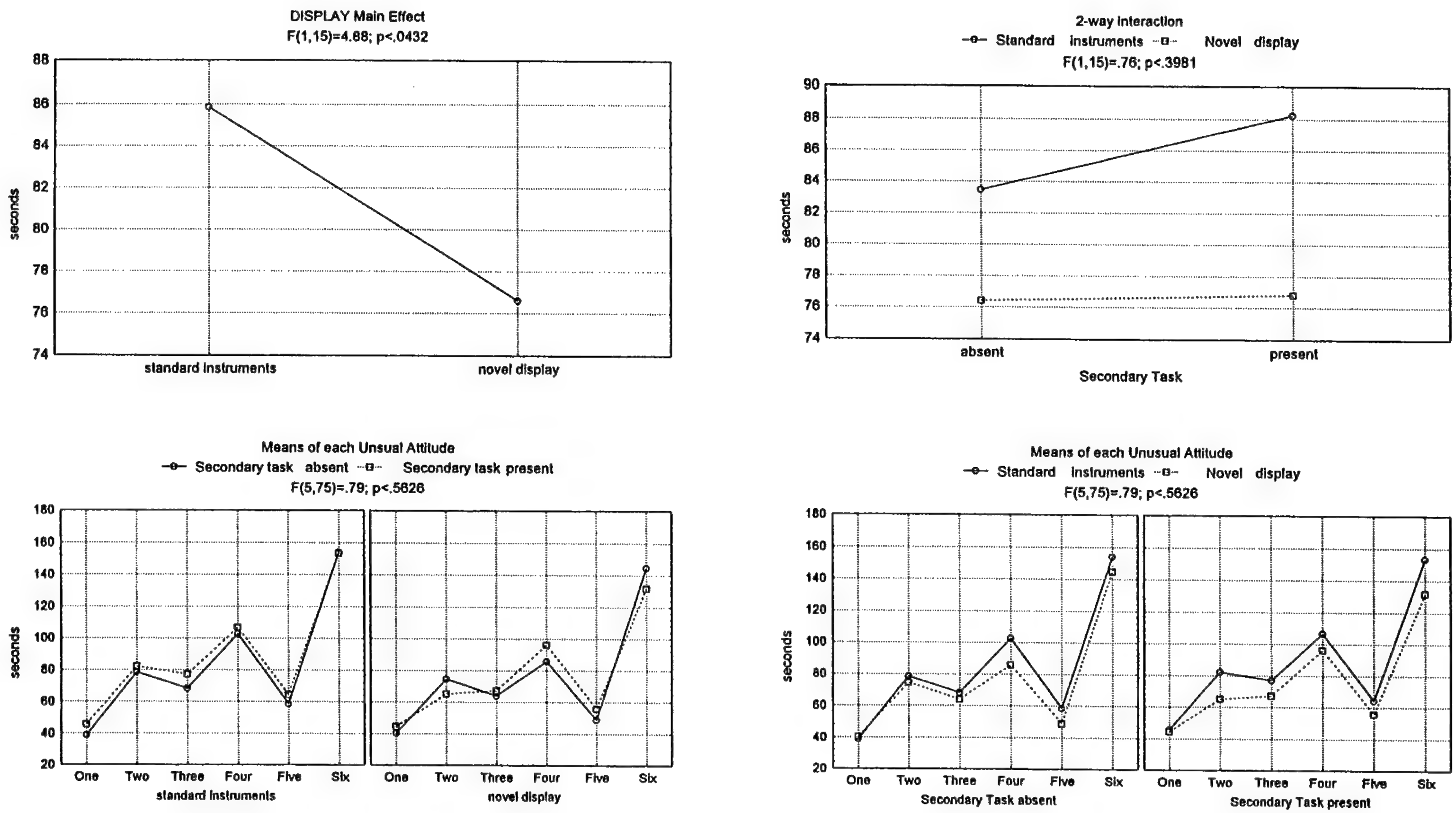


Figure 78. Unusual attitudes - time to achieving all flight parameters within tolerance.

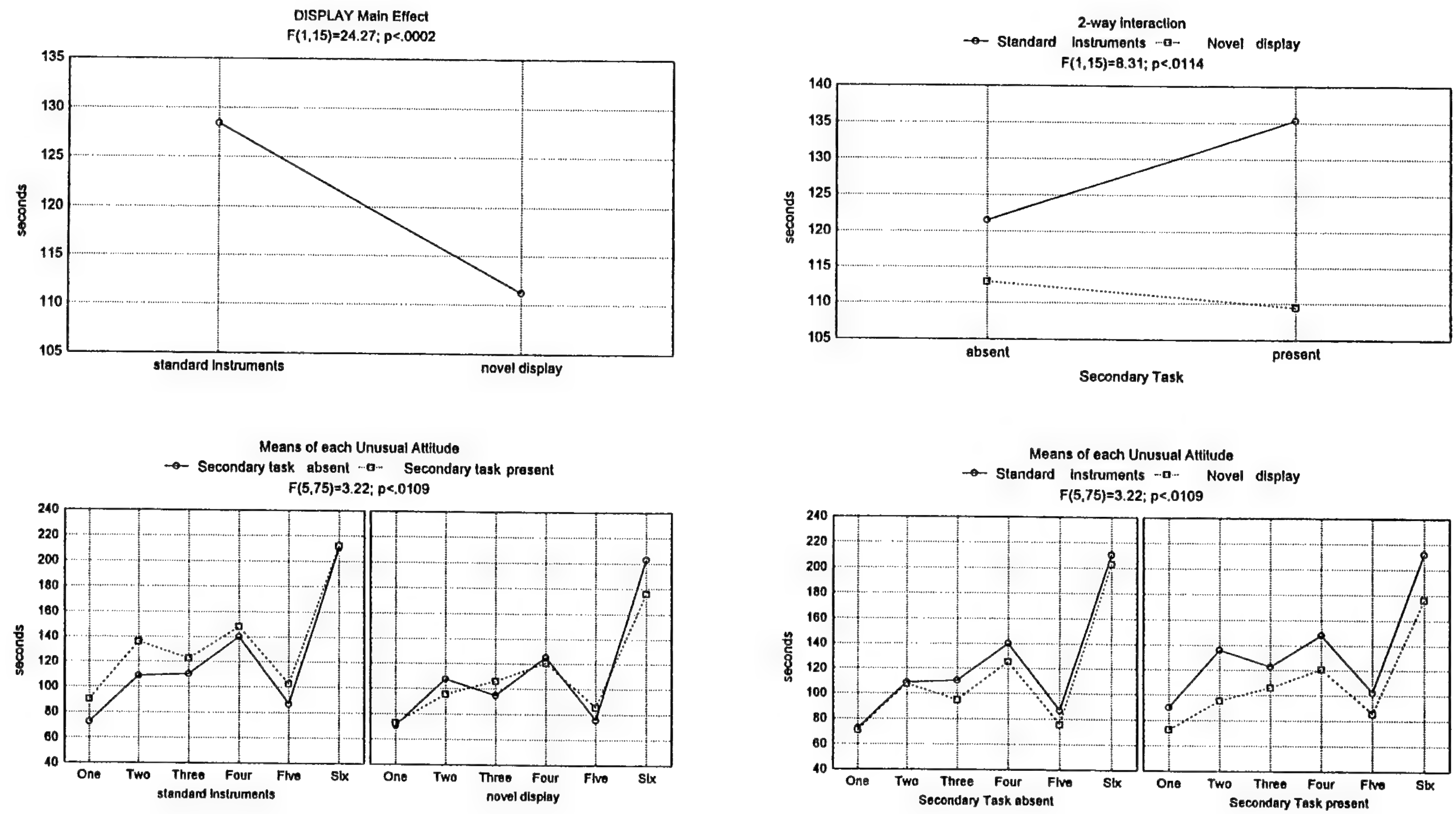
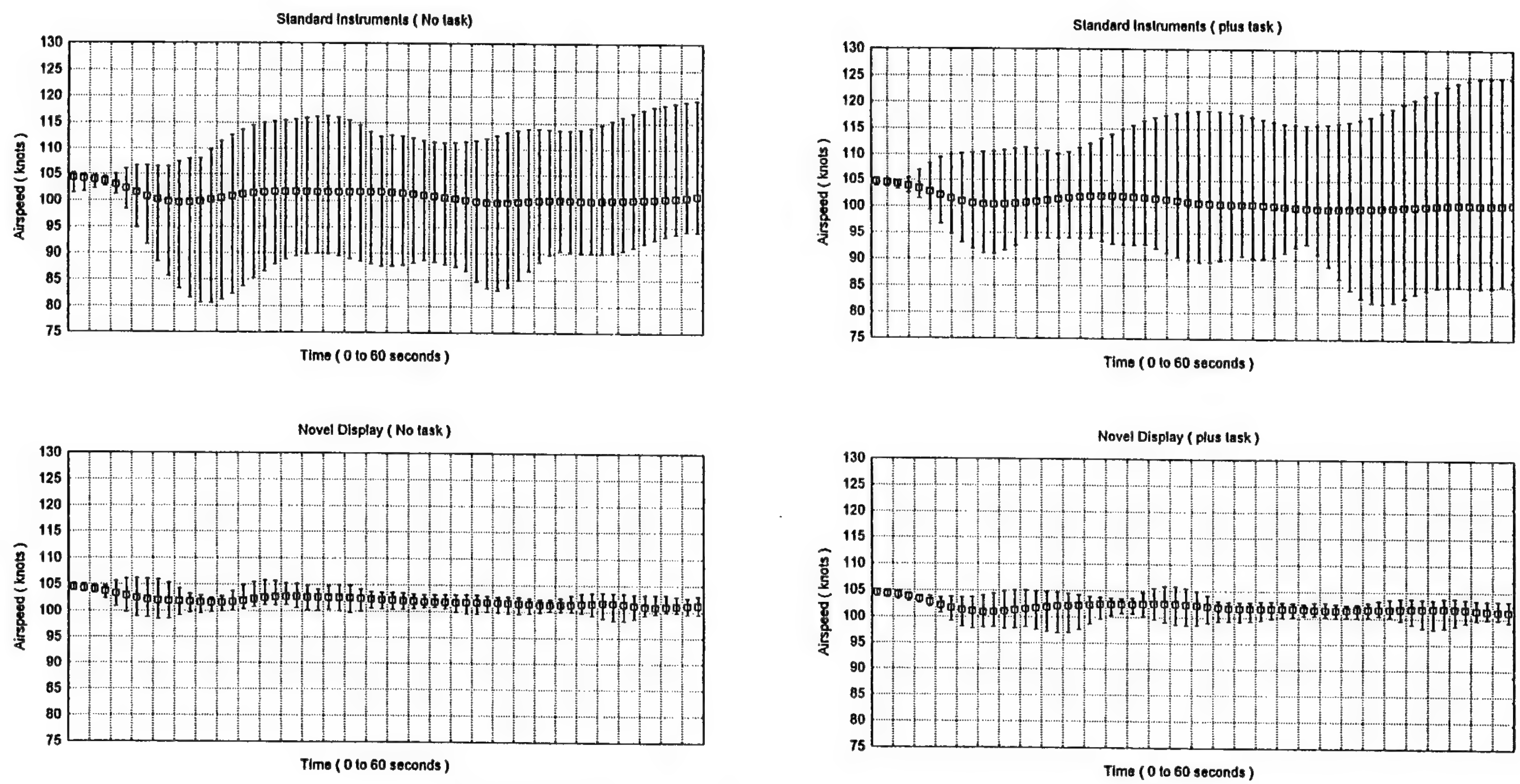


Figure 79. Unusual attitudes - time to maintenance of all flight parameters within tolerance for 30 seconds.

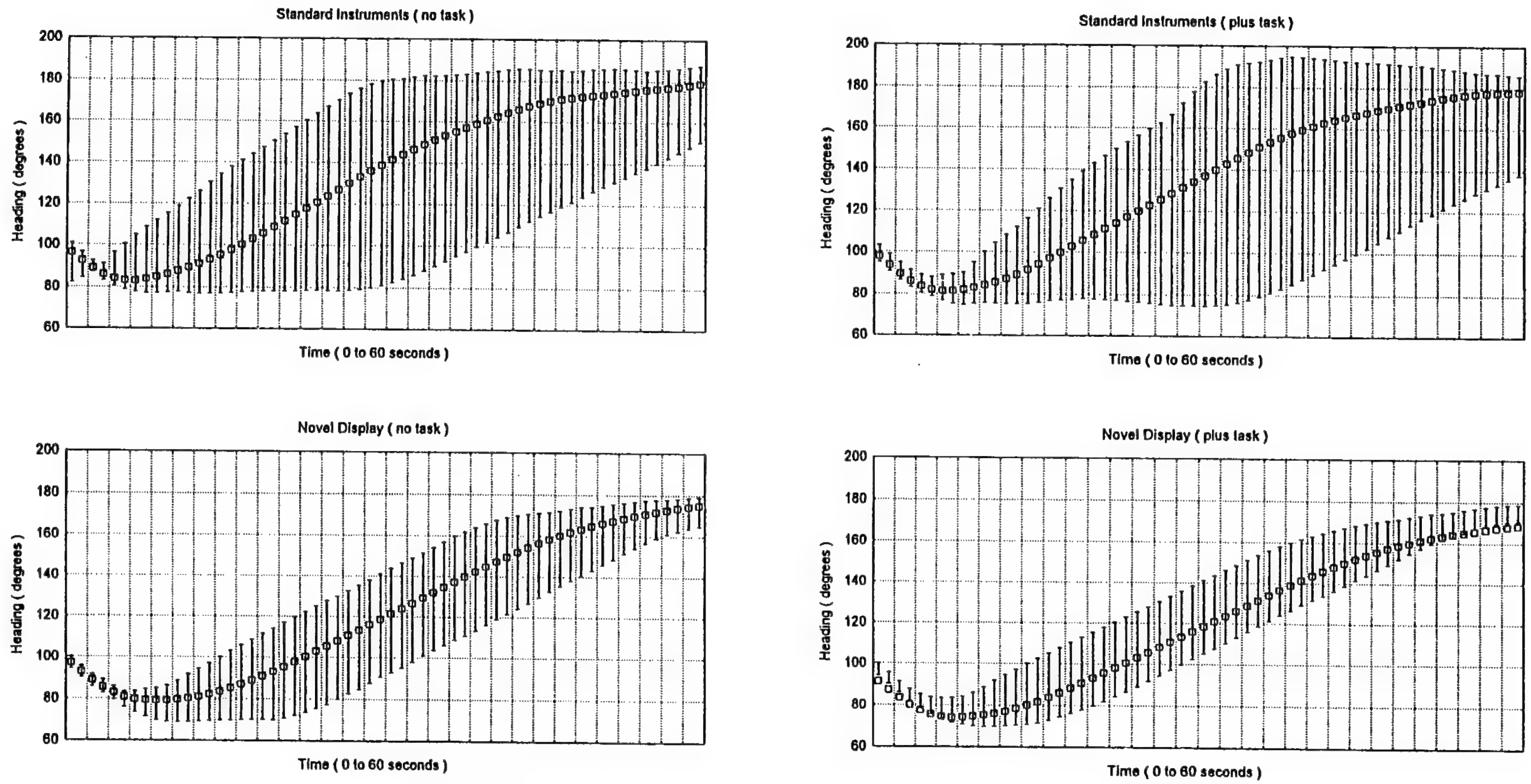
Maneuver: Left roll to 30 degrees. Hold for 10 seconds.



Plot shows mean, maximum, and minimum values

Figure 80. Raw data points for unusual attitude number 1 - airspeed.

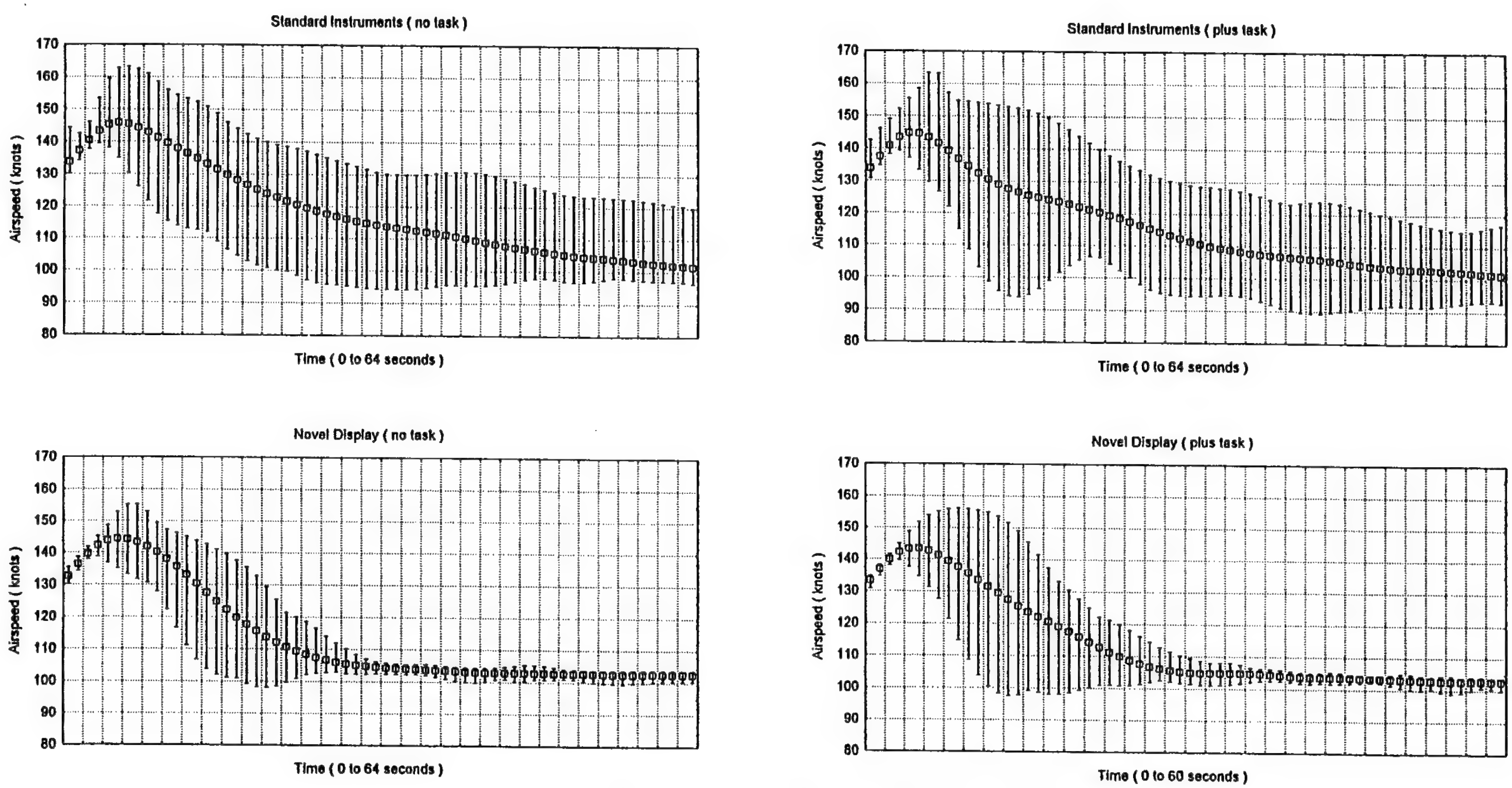
Maneuver: Left roll to 30 degrees. Hold for 10 seconds.



Plot shows mean, maximum, and minimum values

Figure 81. Raw data points for unusual attitude number 1 - heading.

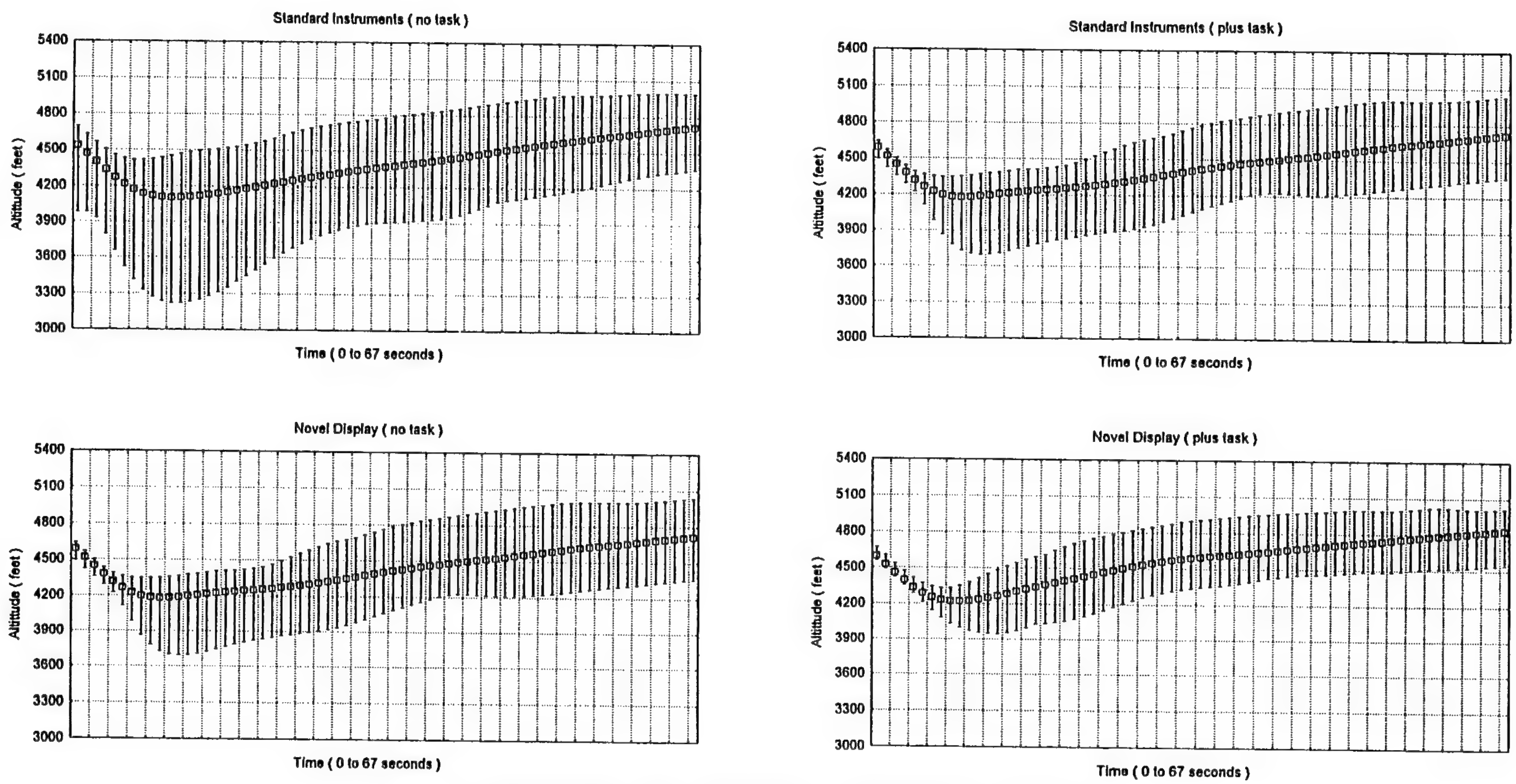
Maneuver: Pitch nose down to -15 degrees. Hold for 5 seconds.



Plot shows mean, maximum, and minimum values

Figure 82. Raw data points for unusual attitude number 2 - airspeed.

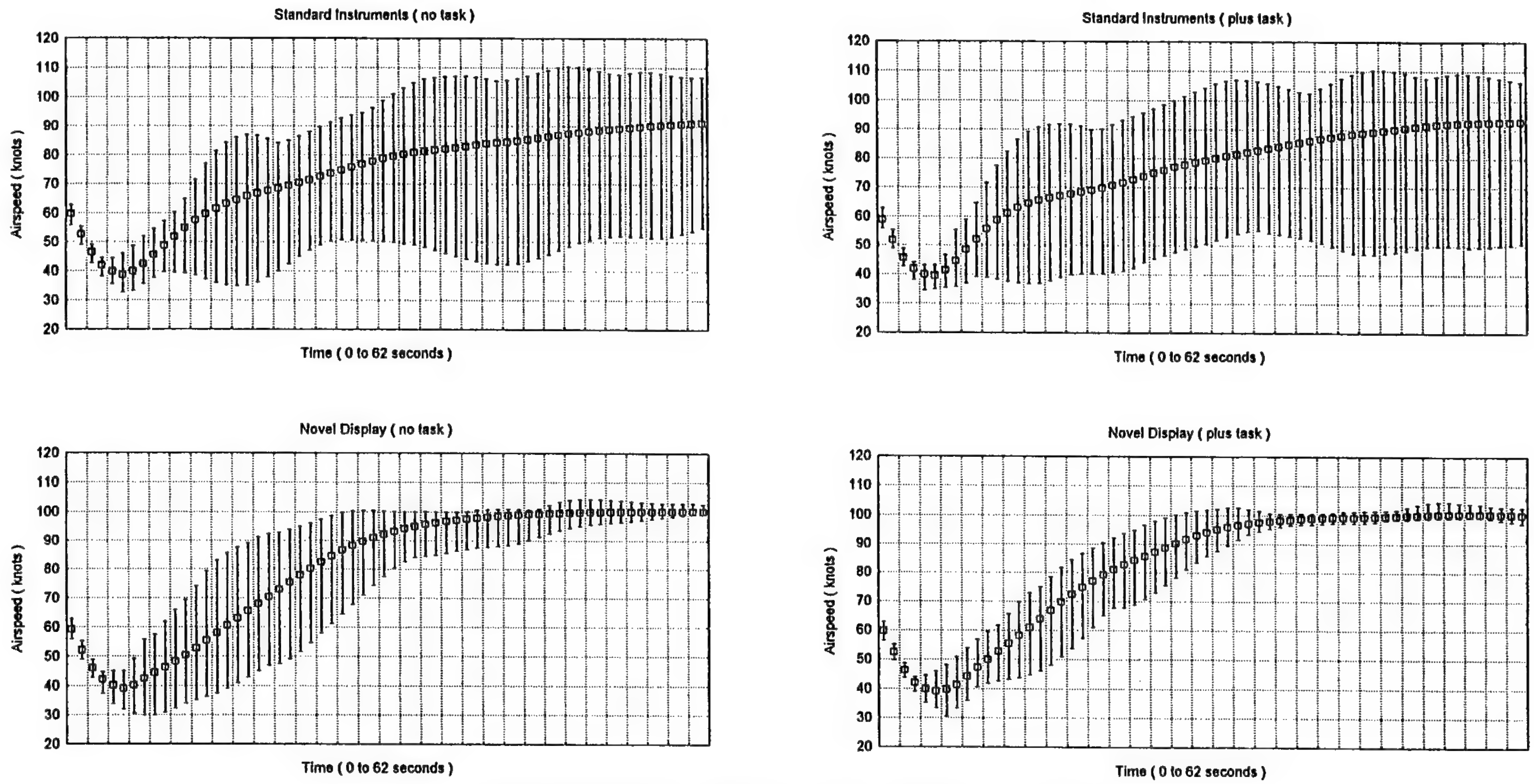
Maneuver: Pitch nose down to -15 degrees. Hold for 5 seconds.



Plot shows mean, maximum, and minimum values

Figure 83. Raw data points for unusual attitude number 2 - altitude.

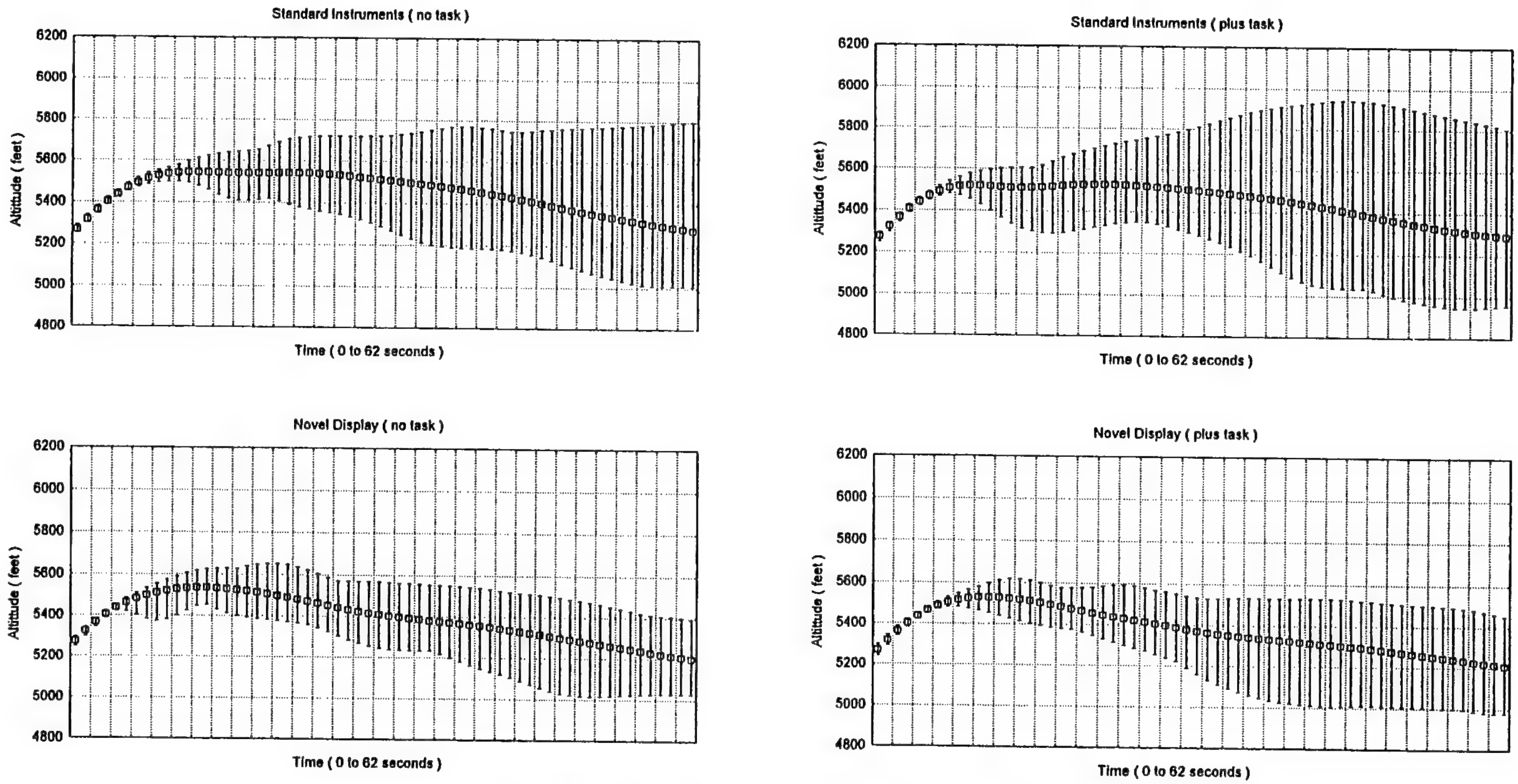
Maneuver: Simultaneously pitch nose up to + 15 degrees and increase torque by 15 percent. Hold for 5 seconds.



Plot shows mean, maximum, and minimum values

Figure 84. Raw data points for unusual attitude number 3 - airspeed.

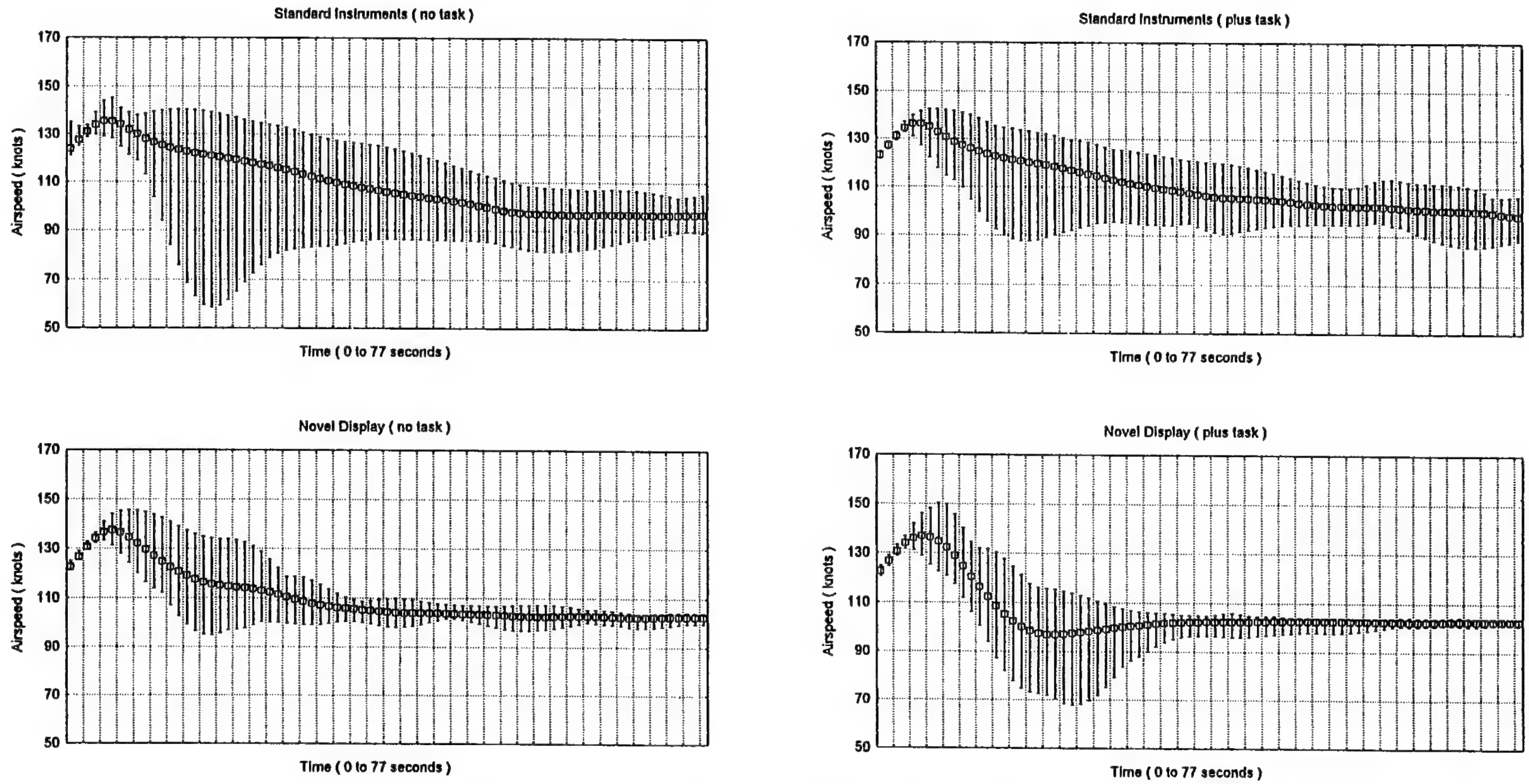
Maneuver: Simultaneously pitch nose up to + 15 degrees and increase torque by 15 percent. Hold for 5 seconds.



Plot shows mean, maximum, and minimum values

Figure 85. Raw data points for unusual attitude number 3 - altitude.

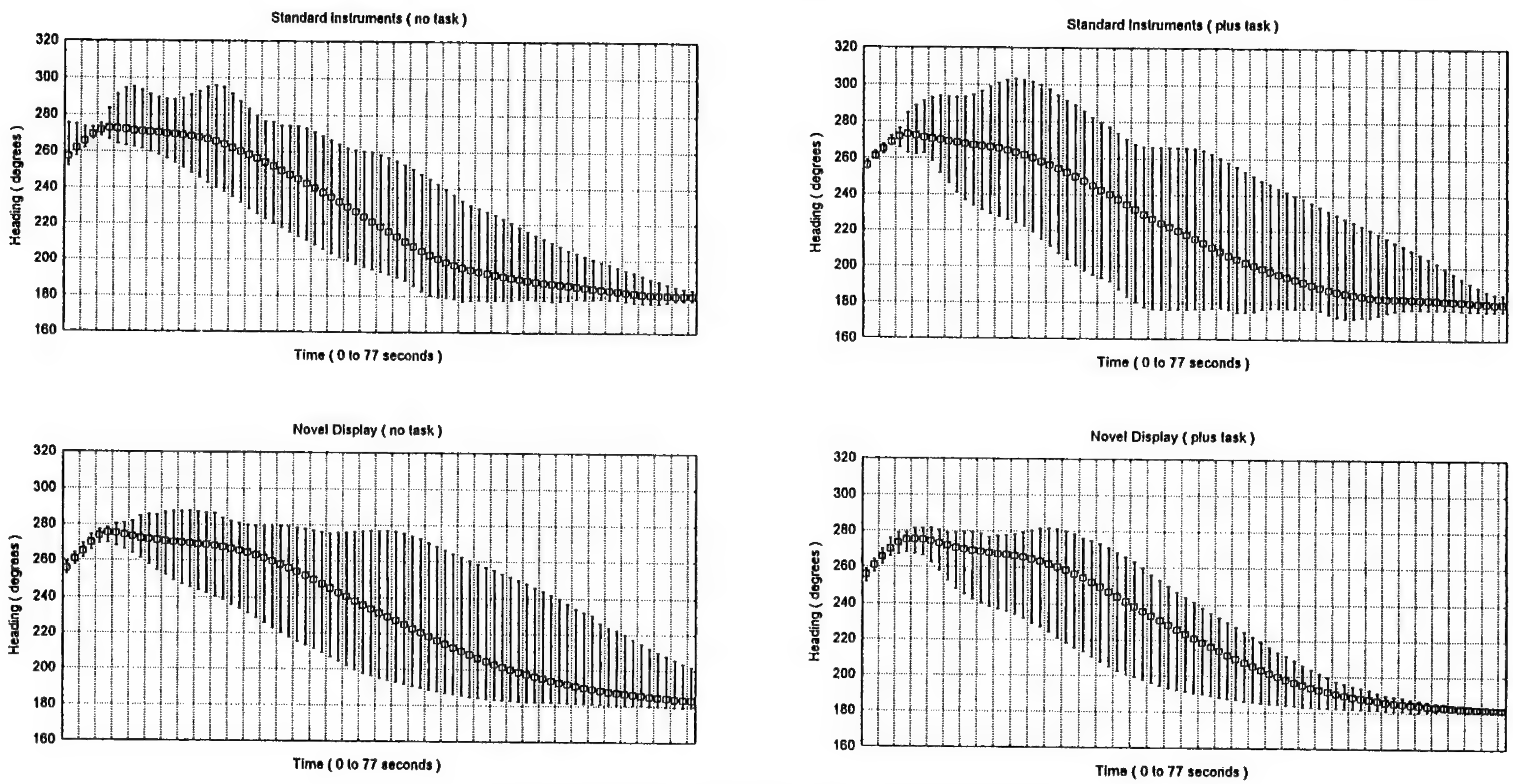
Maneuver: Right roll to 30 degrees. Then simultaneously pitch nose down to -10 degrees and decrease Tq by 25 percent. Hold for 3 seconds.



Plot shows mean, maximum, and minimum values

Figure 86. Raw data points for unusual attitude number 4 - airspeed.

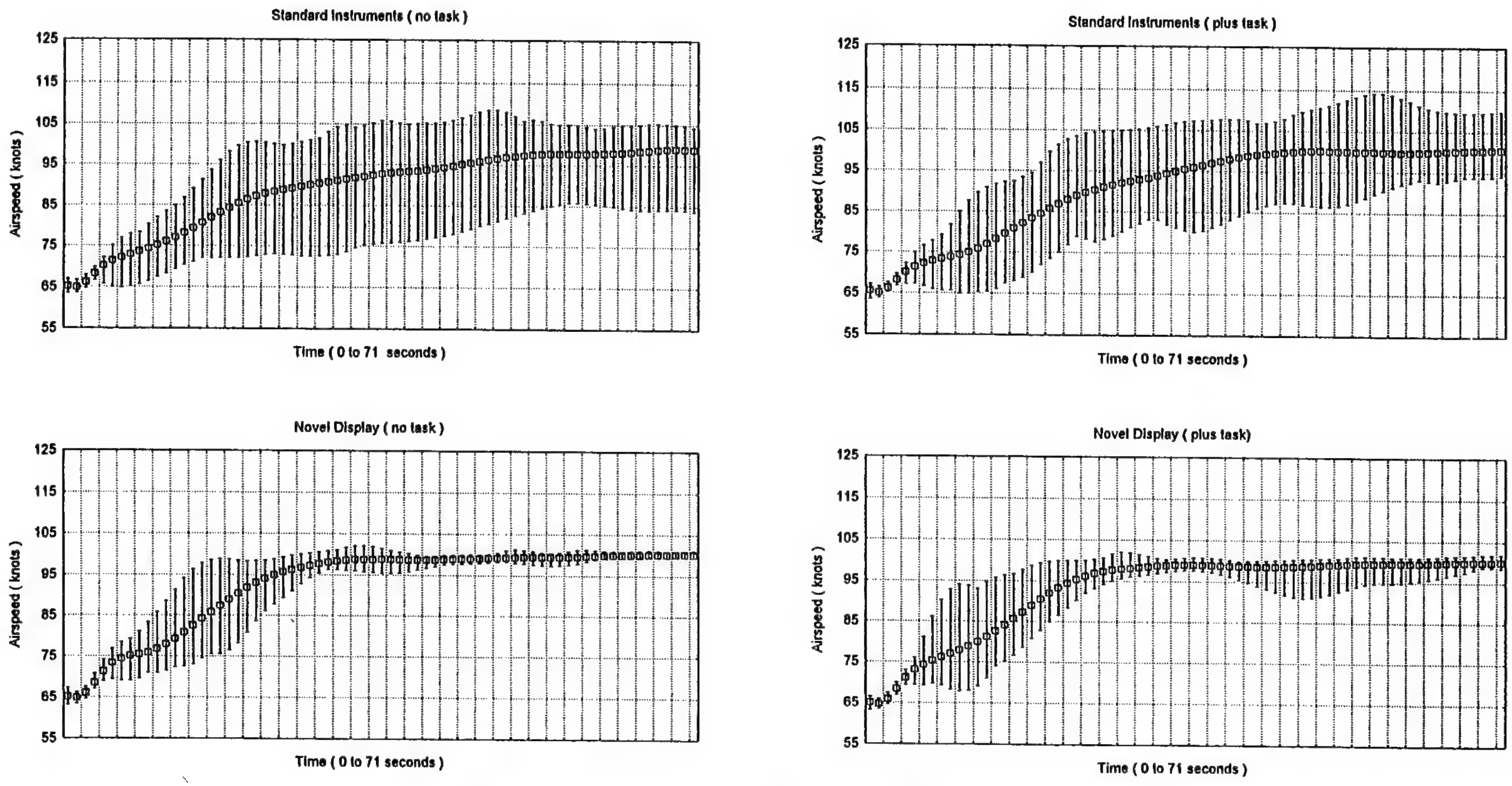
Maneuver: Right roll to 30 degrees. Then simultaneously pitch nose down to -10 degrees and decrease Tq by 25 percent. Hold for 3 seconds.



Plot shows mean, maximum, and minimum values

Figure 87. Raw data points for unusual attitude number 4 - heading.

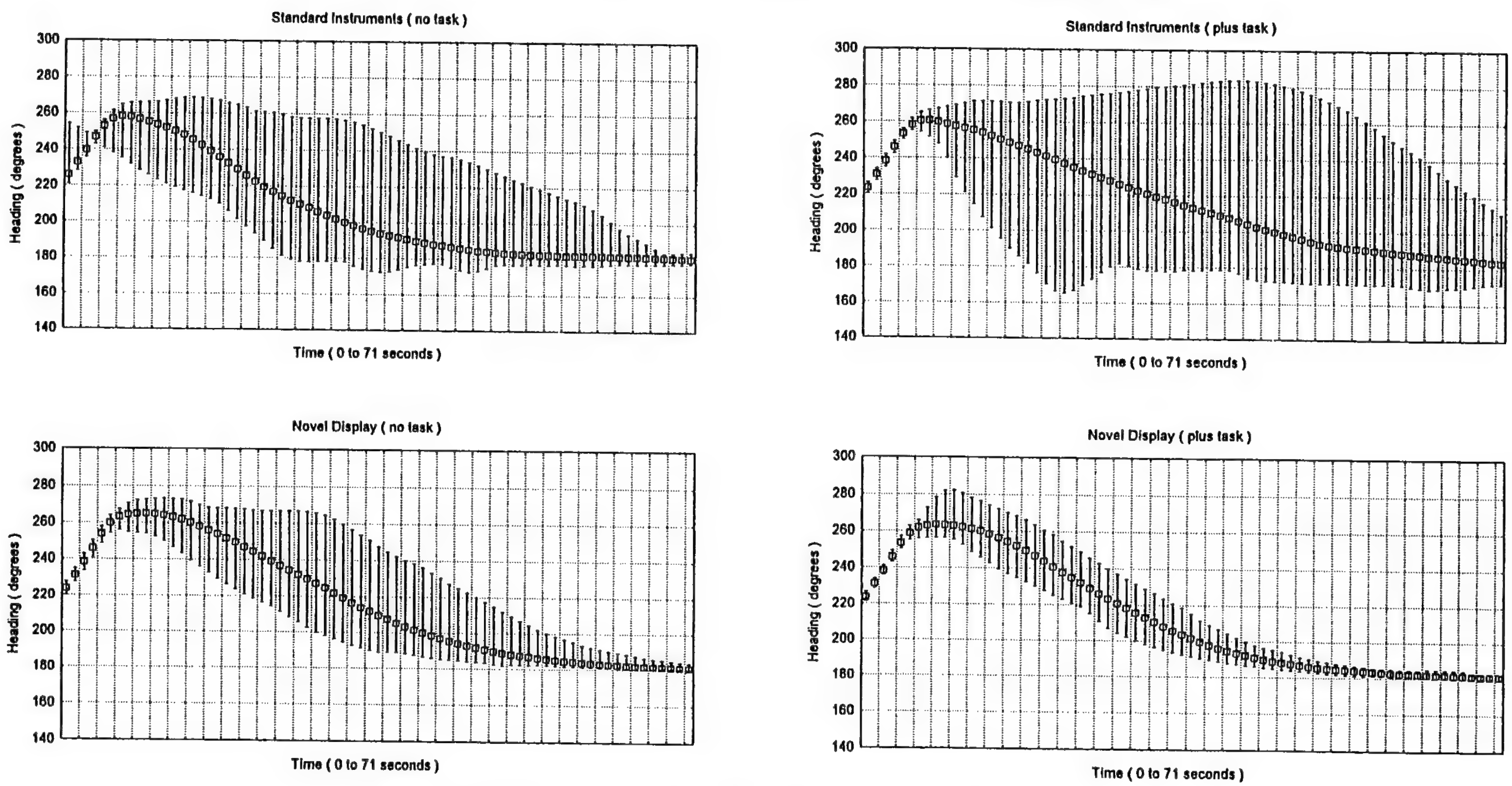
Maneuver: Simultaneous right roll to 30 degrees, pitch nose up to +15 degrees and increase Tq by 15 percent. Hold for 3 seconds.



Plot shows mean, maximum, and minimum values

Figure 88. Raw data points for unusual attitude number 5 - airspeed.

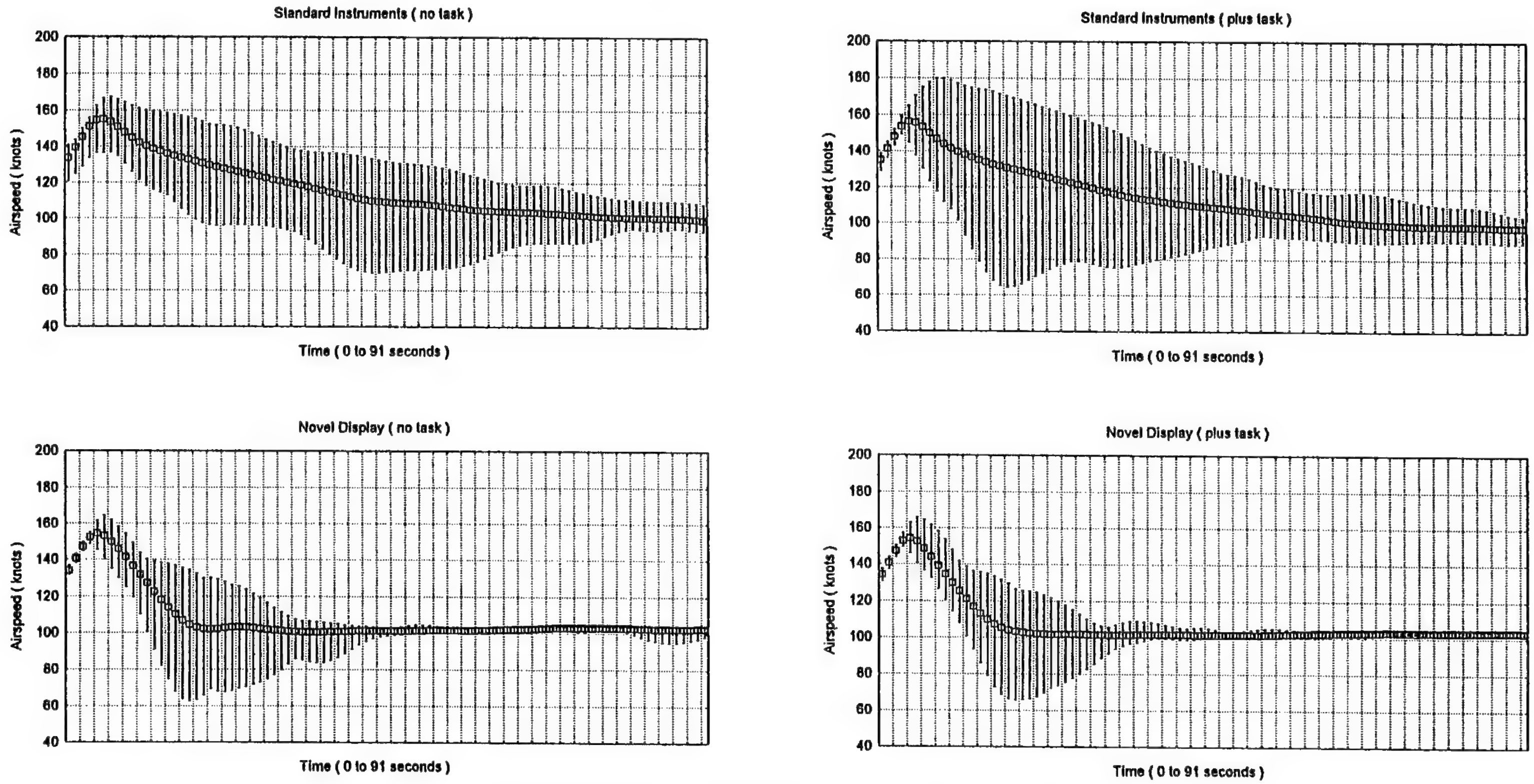
Maneuver: Simultaneous right roll to 30 degrees, pitch nose up to +15 degrees and increase Tq by 15 percent. Hold for 3 seconds.



Plot shows mean, maximum, and minimum values

Figure 89. Raw data points for unusual attitude number 5 - heading.

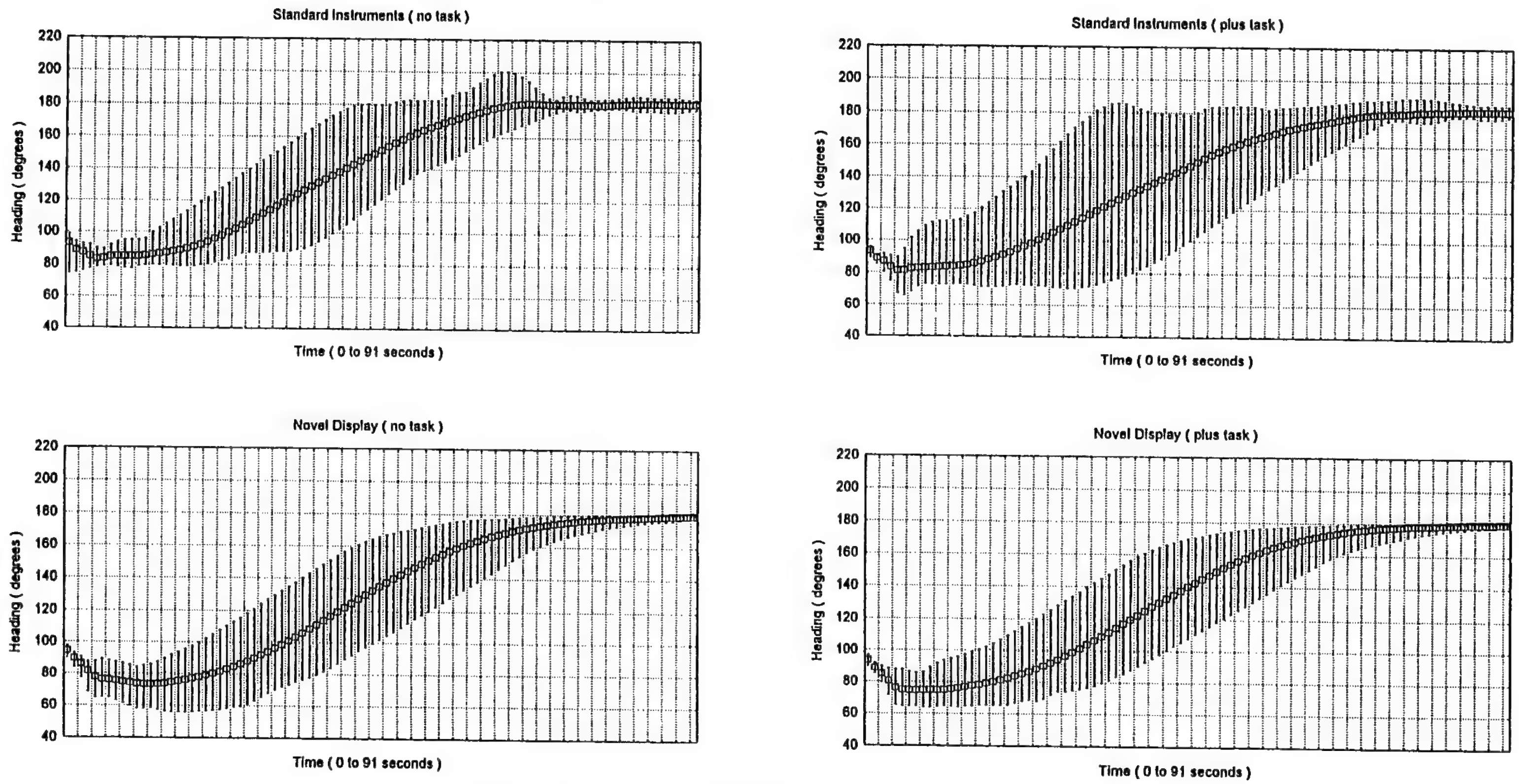
Maneuver: Simultaneous left roll to 30 degrees, reduce Tq to 20 percent. Then pitch nose down to -20 degrees. Hold for 3 seconds.



Plot shows mean, maximum, and minimum values

Figure 90. Raw data points for unusual attitude number 6 - airspeed.

Maneuver: Simultaneous left roll to 30 degrees, reduce Tq to 20 percent. Then pitch nose down to -20 degrees. Hold for 3 seconds.



Plot shows mean, maximum, and minimum values

Figure 91. Raw data points for unusual attitude number 6 - heading.

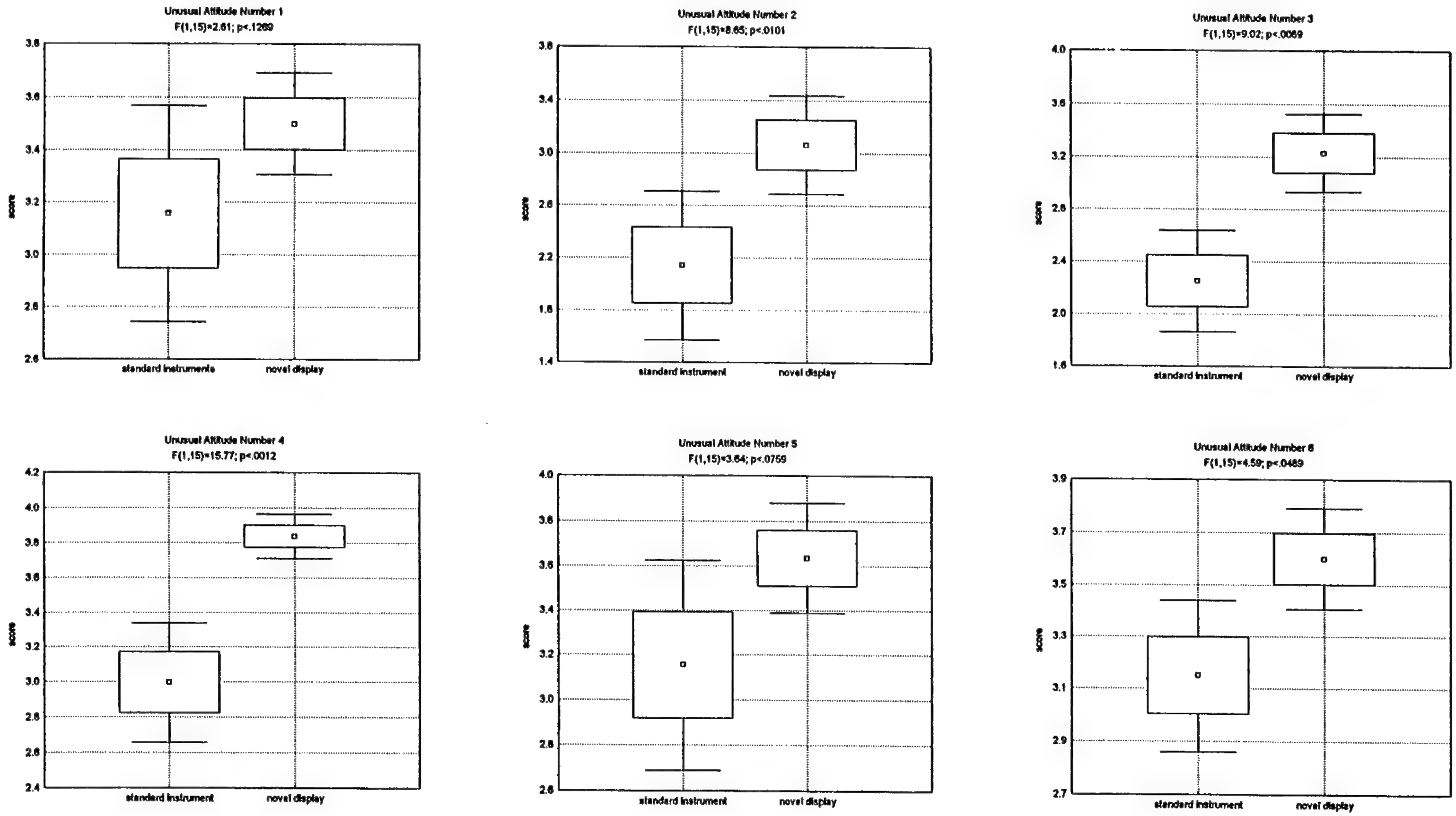


Figure 93. Initial cyclic stick movement (individual unusual attitudes).
(Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

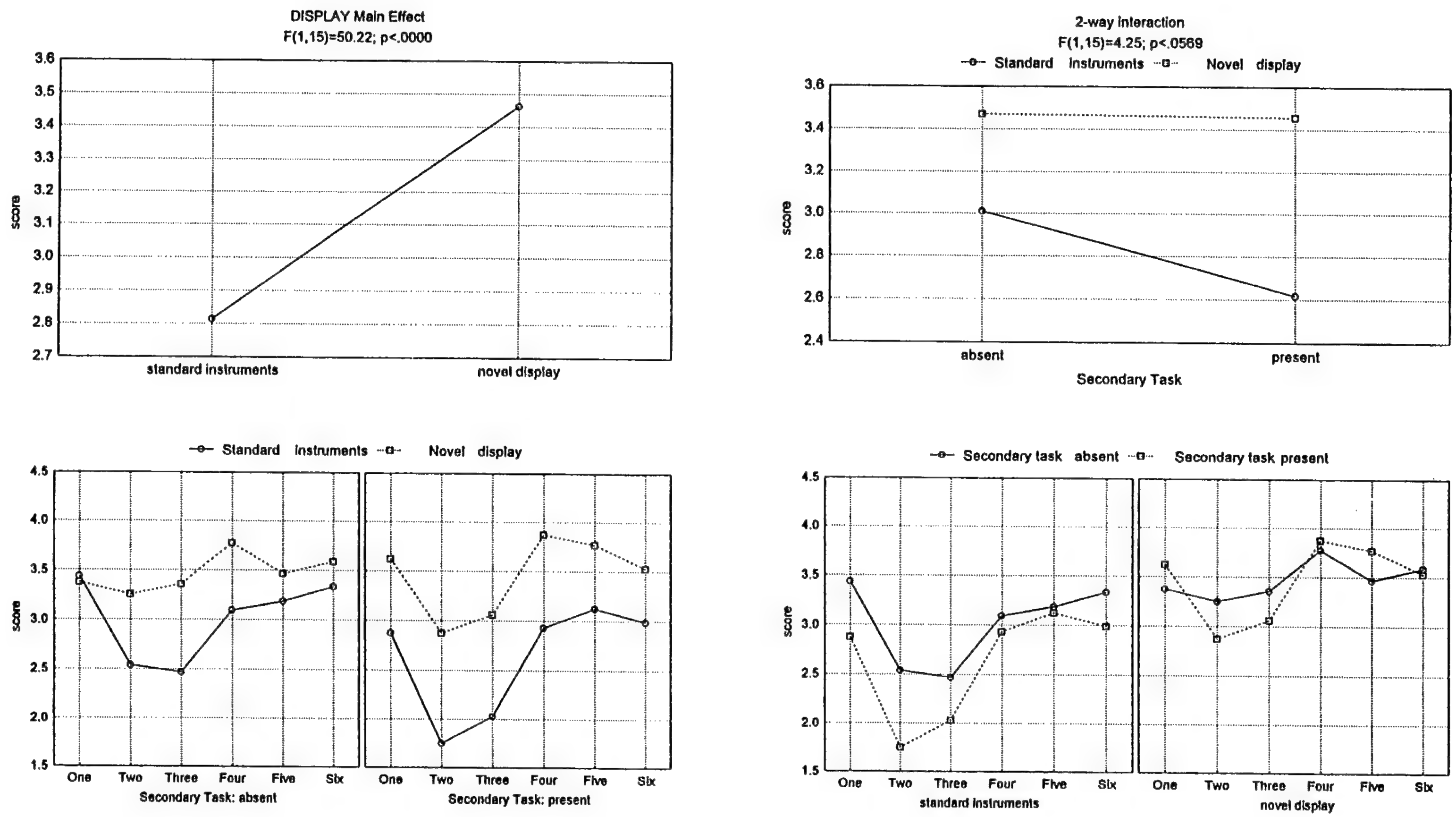


Figure 94. Initial cyclic stick movement (interactions).
(Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

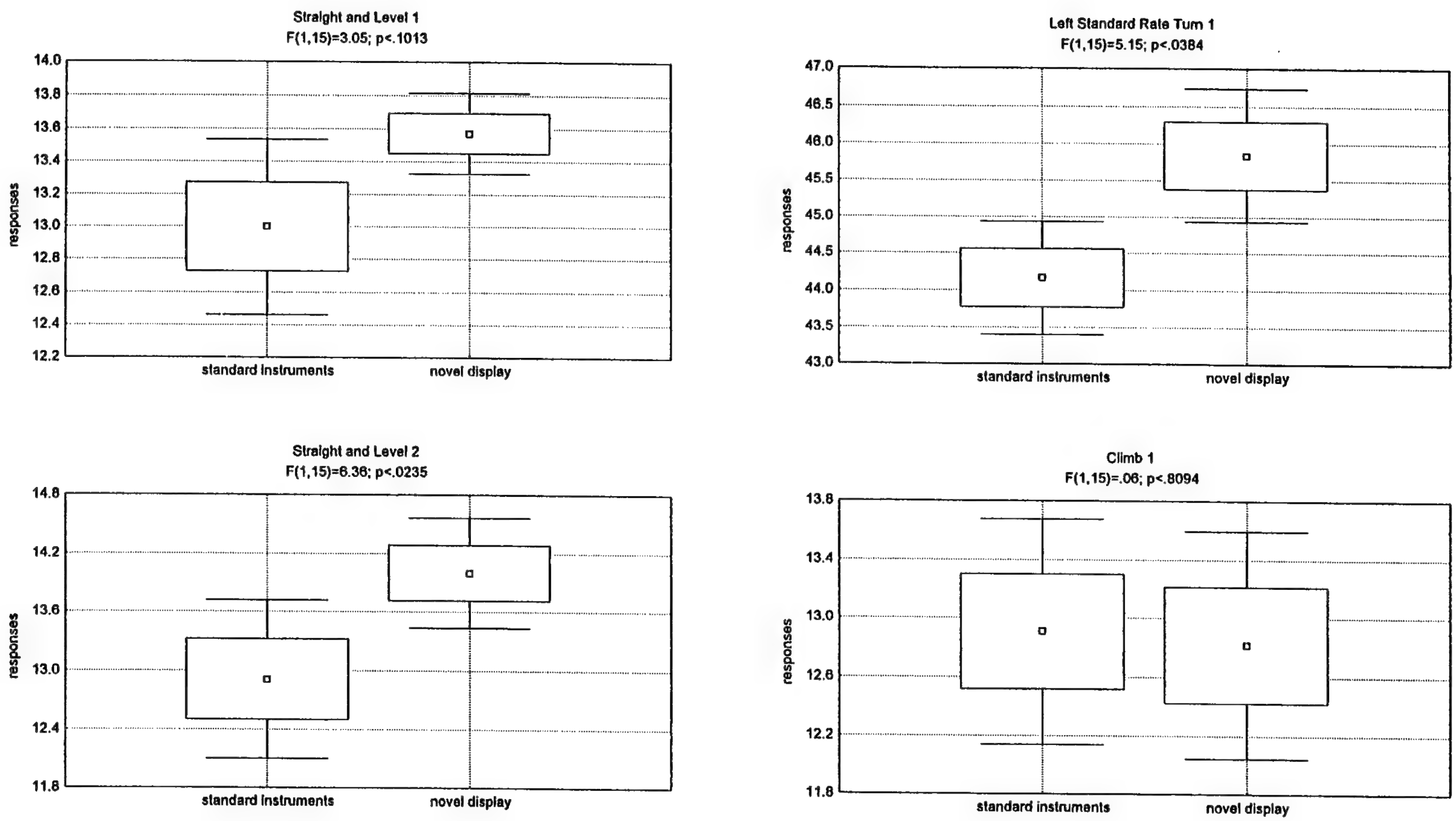


Figure 95. Total responses to presented tones. AFCS ON maneuvers (1). (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

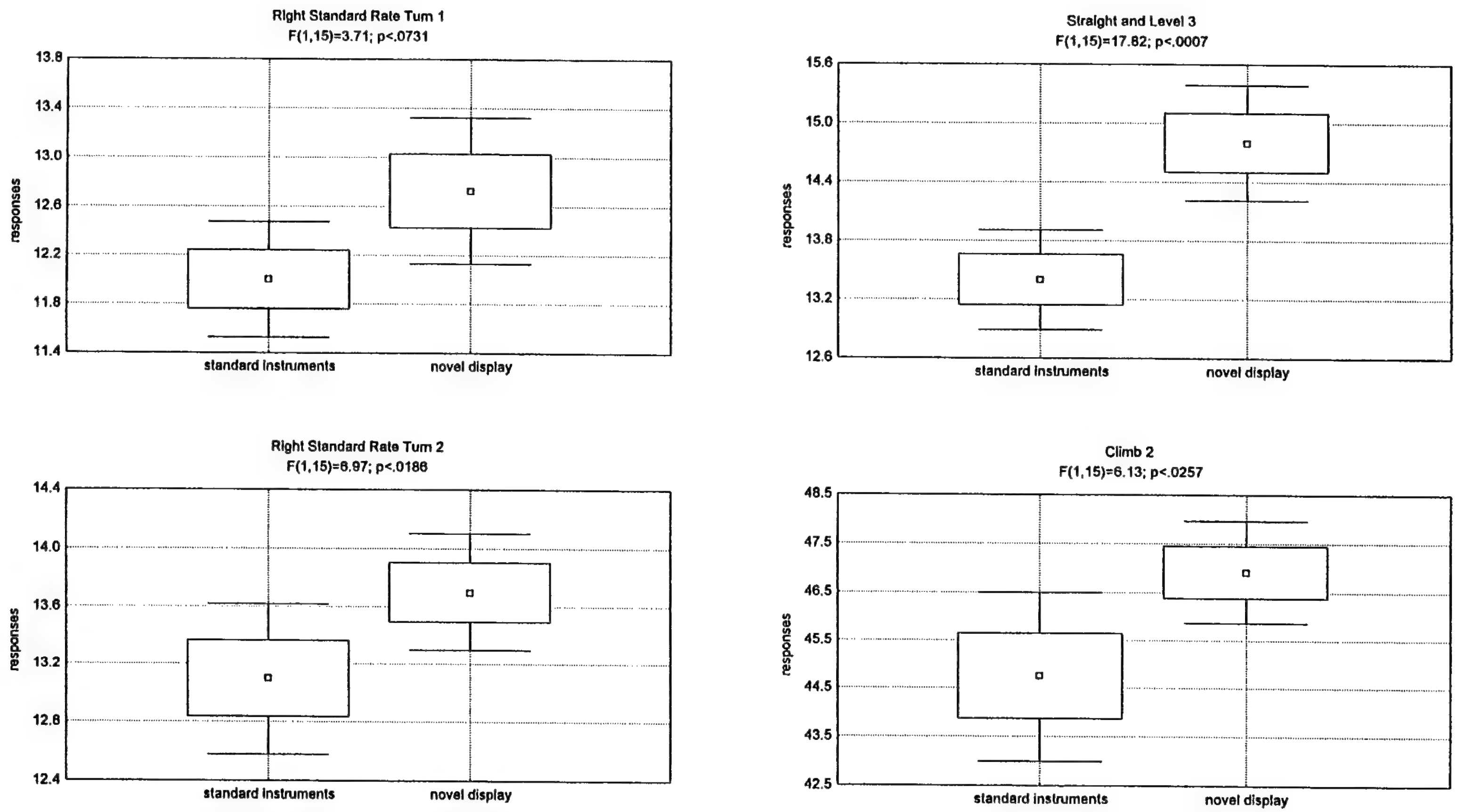


Figure 96. Total responses to presented tones. AFCS ON maneuvers (2).
(Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

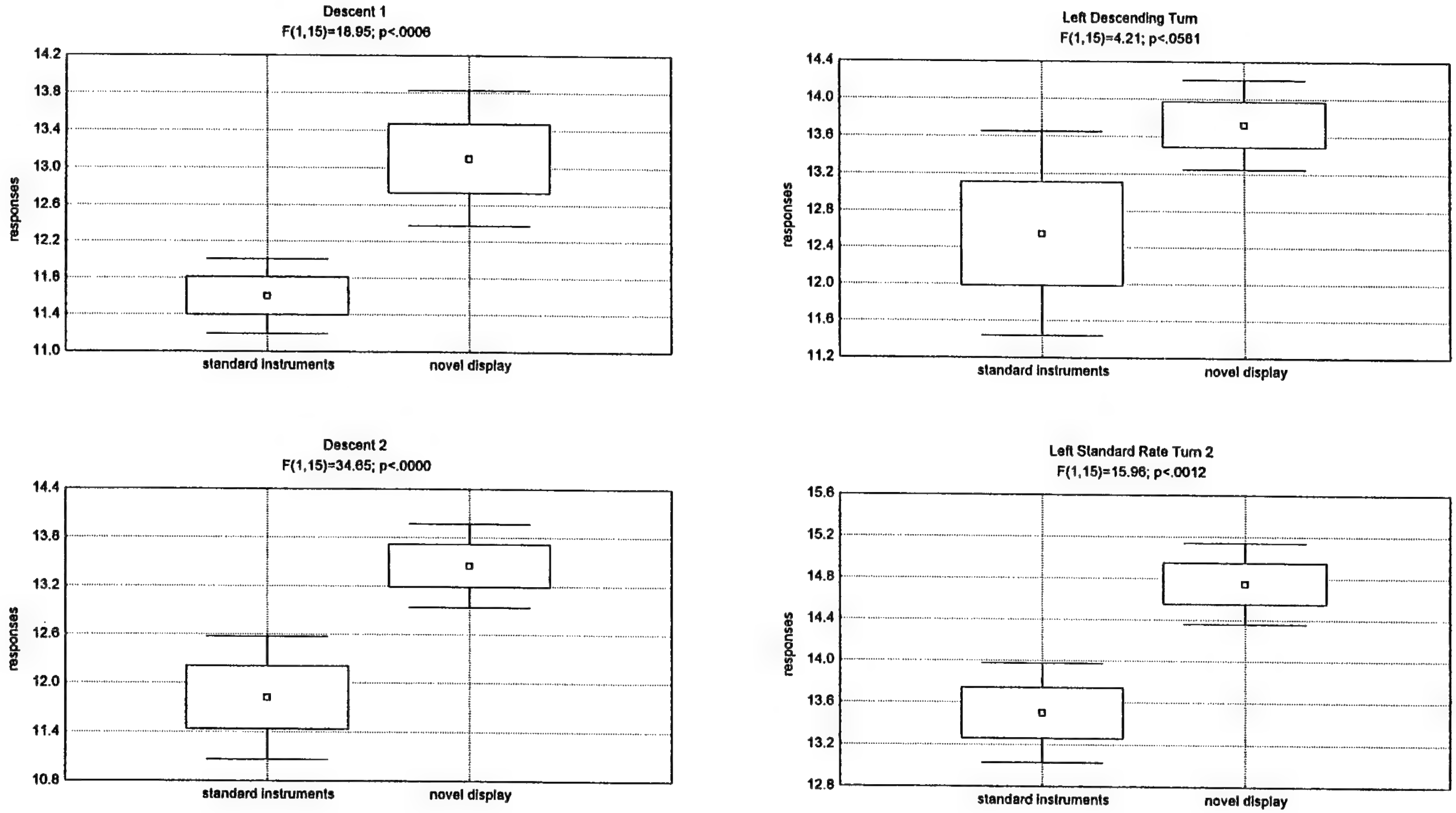


Figure 97. Total responses to presented tones. AFCS OFF maneuvers (1).
(Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

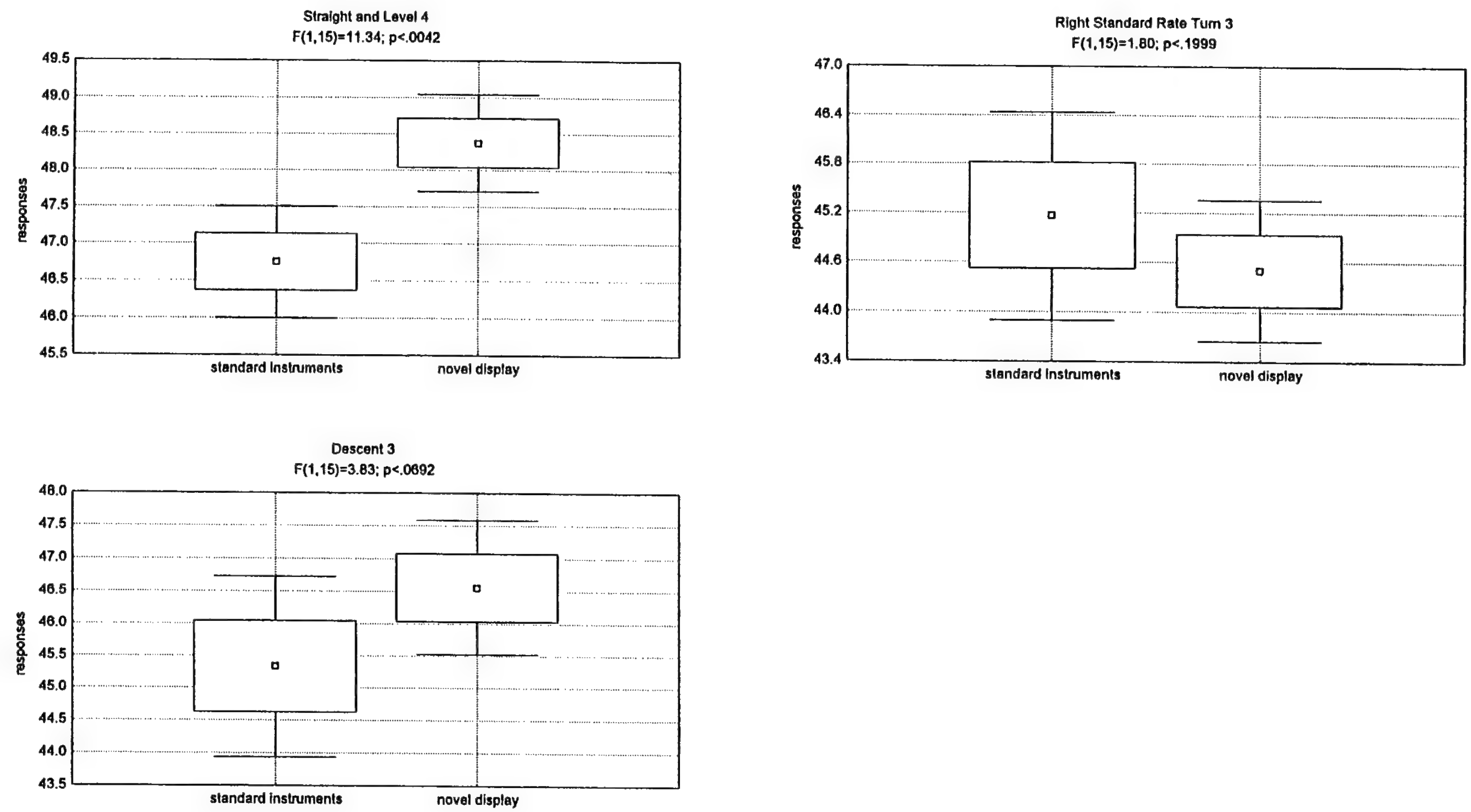


Figure 98. Total responses to presented tones. AFCS OFF maneuvers (2). (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

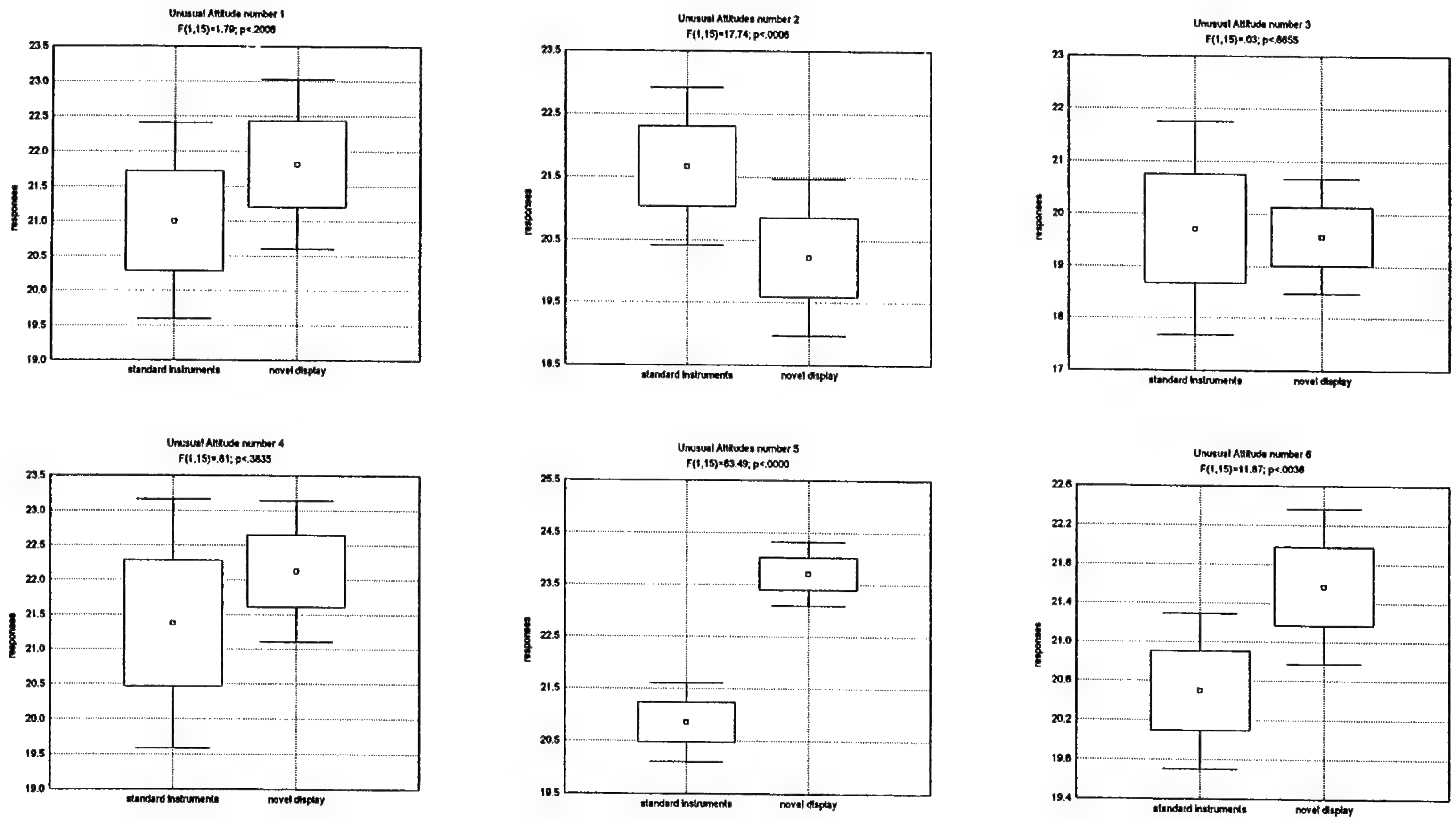


Figure 99. Total responses to presented tones for unusual attitudes.
(Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

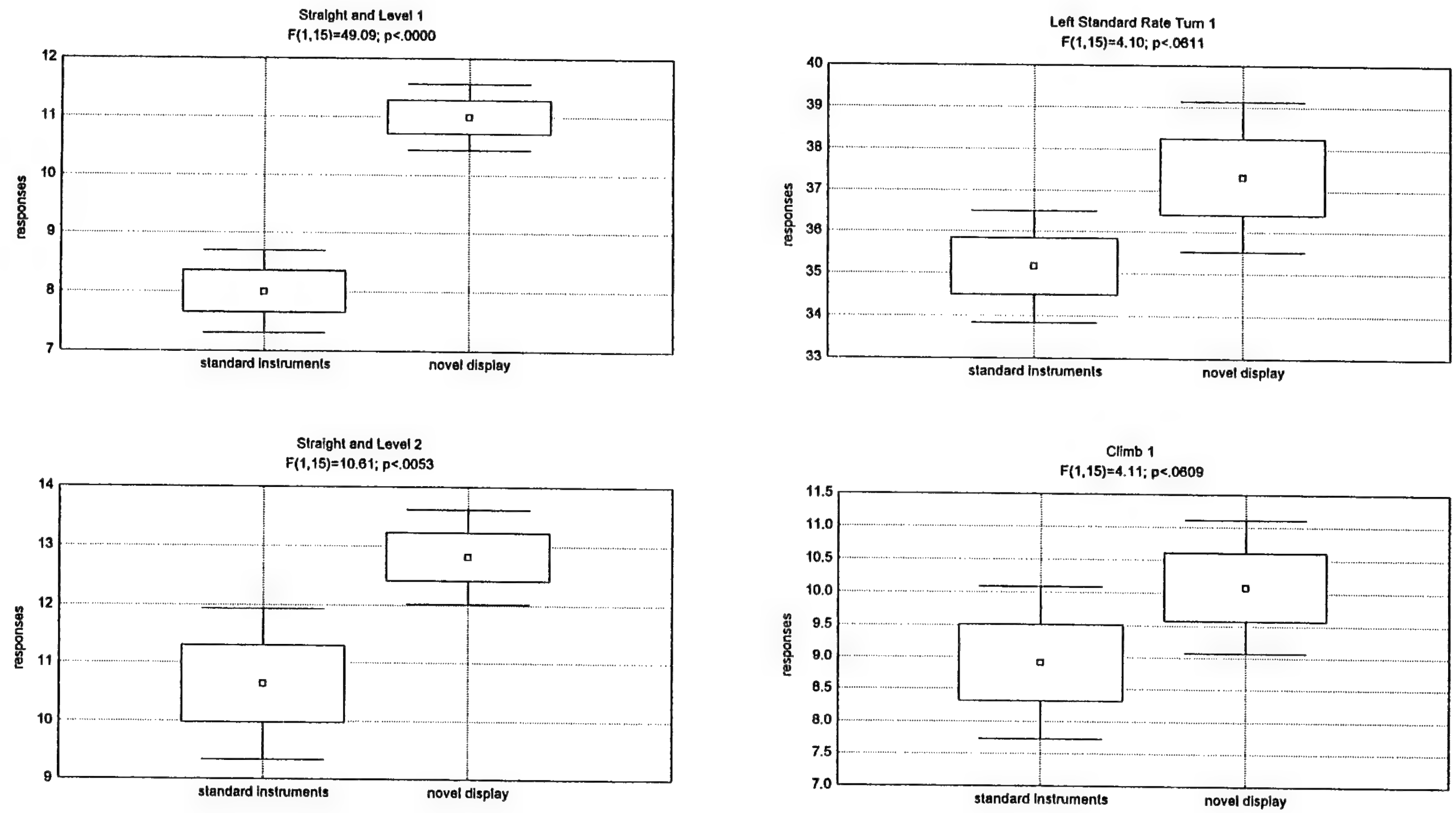


Figure 100. Correct responses to presented tones. AFCS ON maneuvers (1). (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

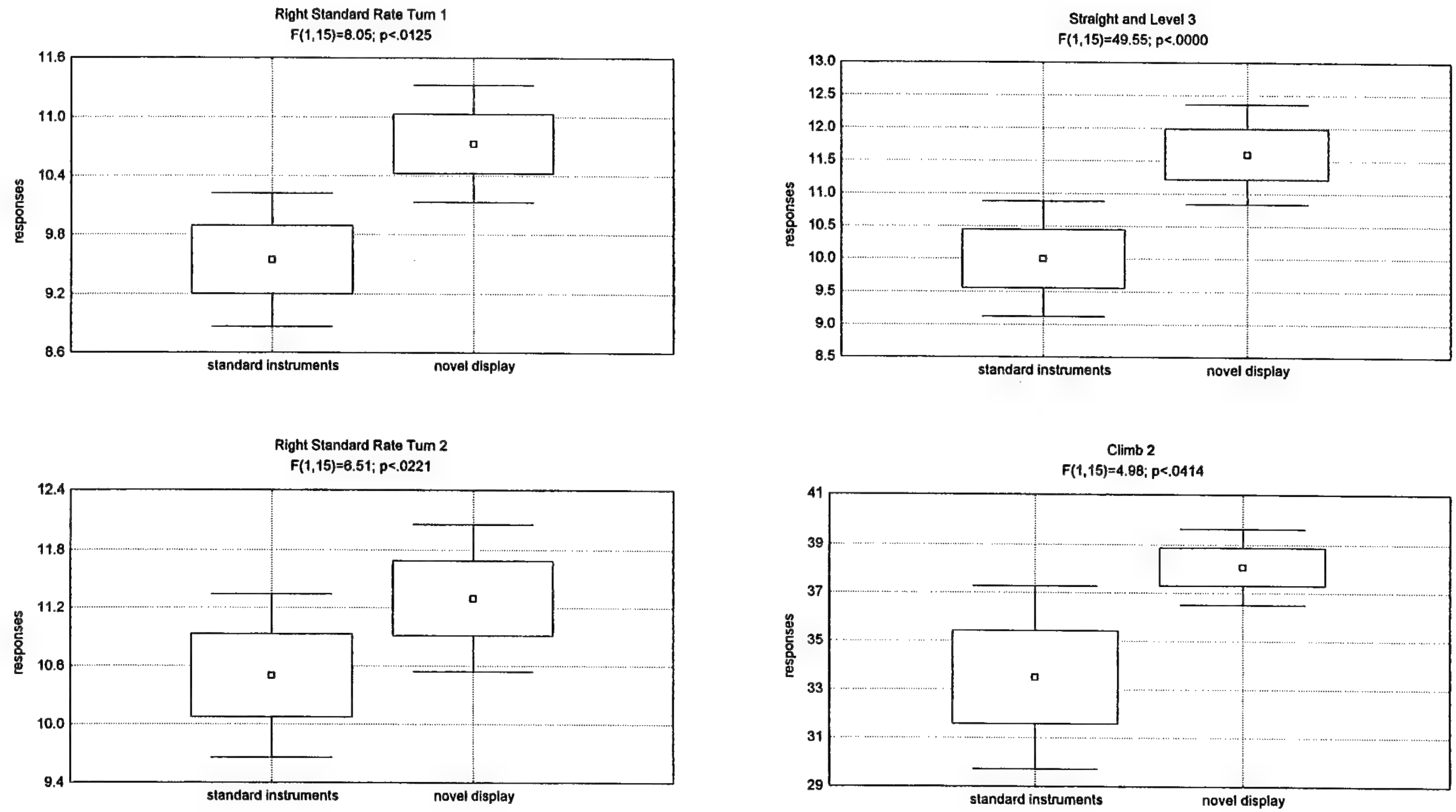


Figure 101. Correct responses to presented tones. AFCS ON maneuvers. (2) (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

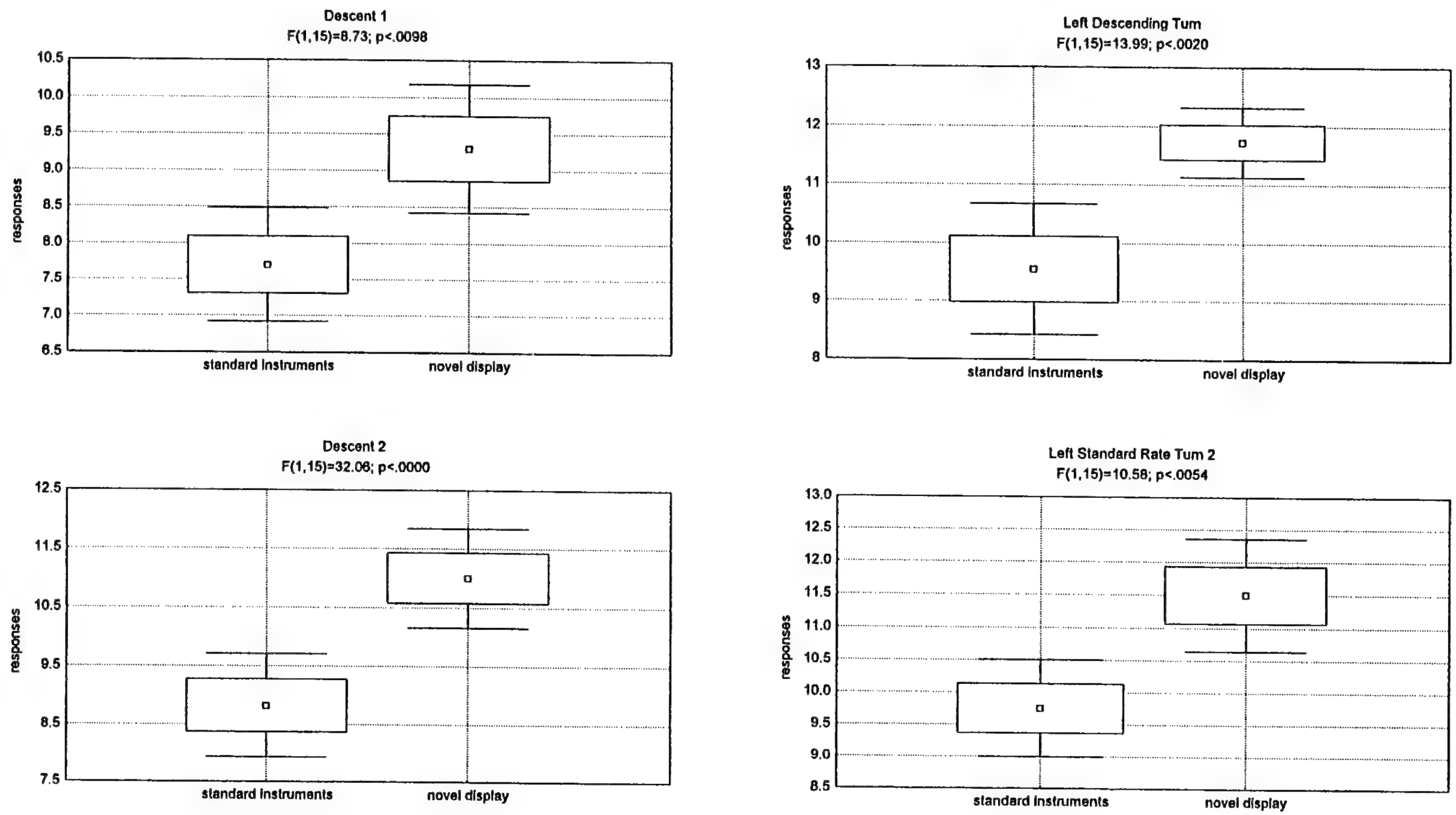


Figure 102. Correct responses to presented tones. AFCS OFF maneuvers (1). (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

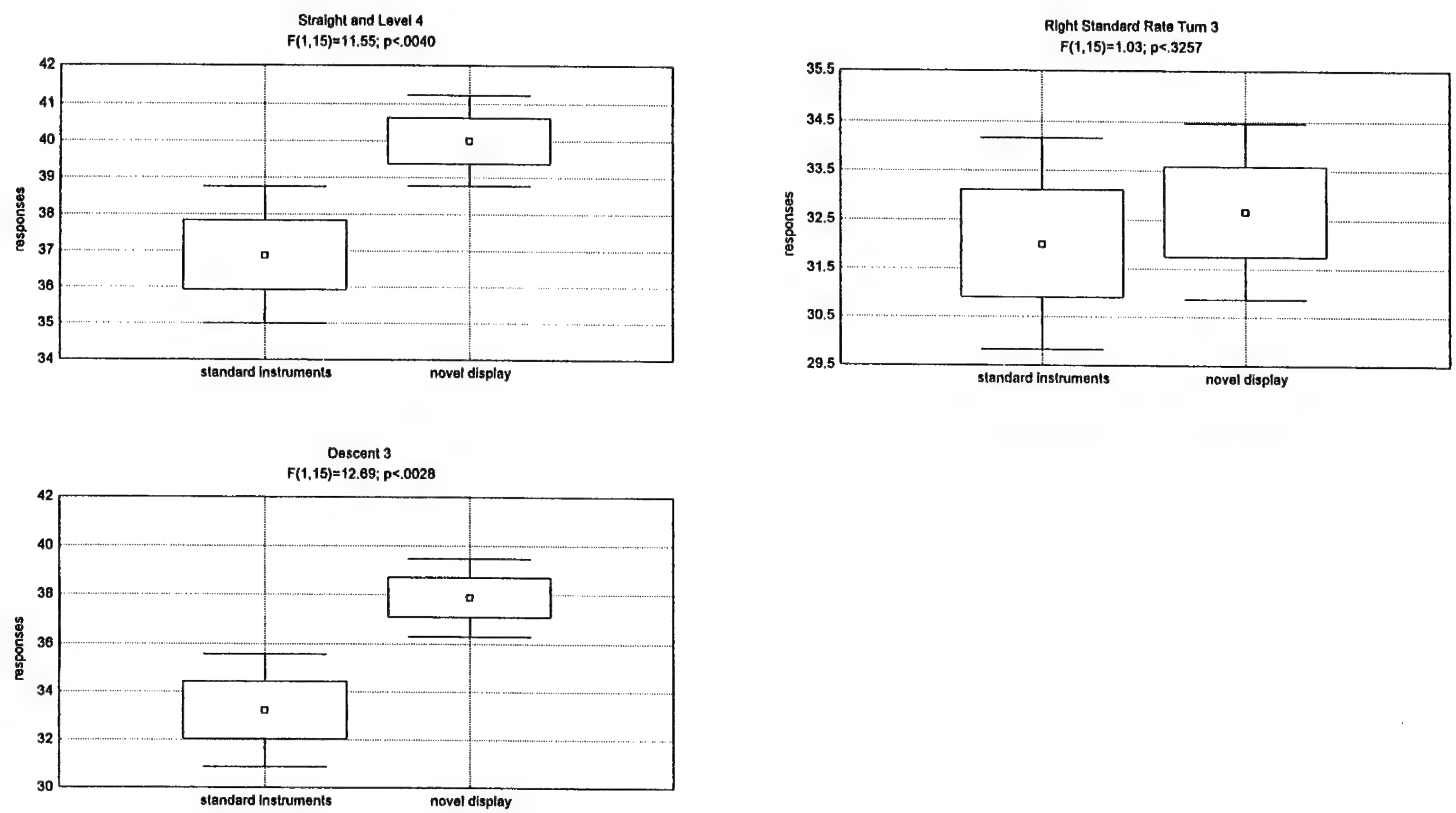


Figure 103. Correct responses to presented tones. AFCS OFF maneuvers (2). (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

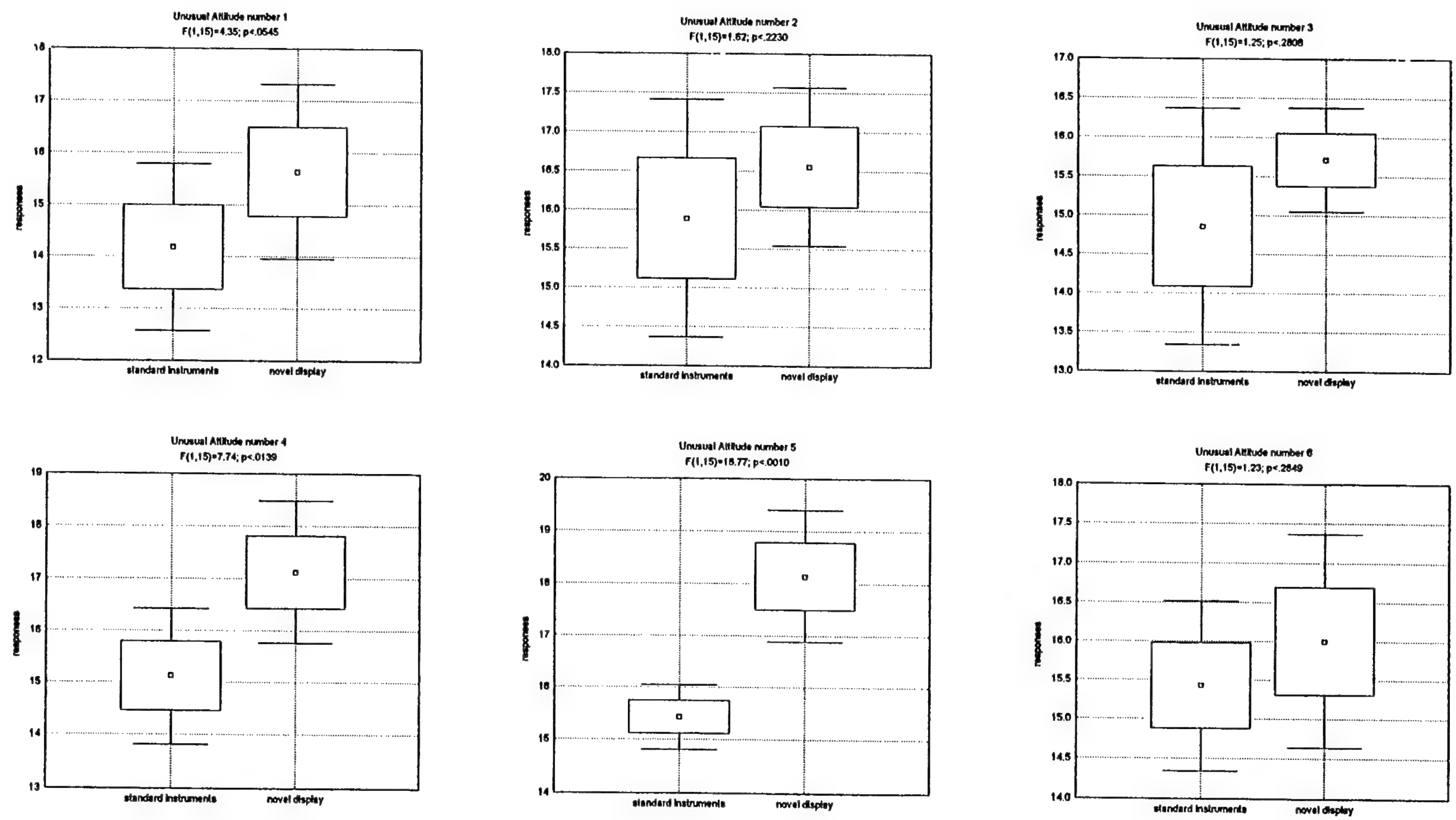


Figure 104. Correct responses to presented tones for unusual attitudes.
(Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

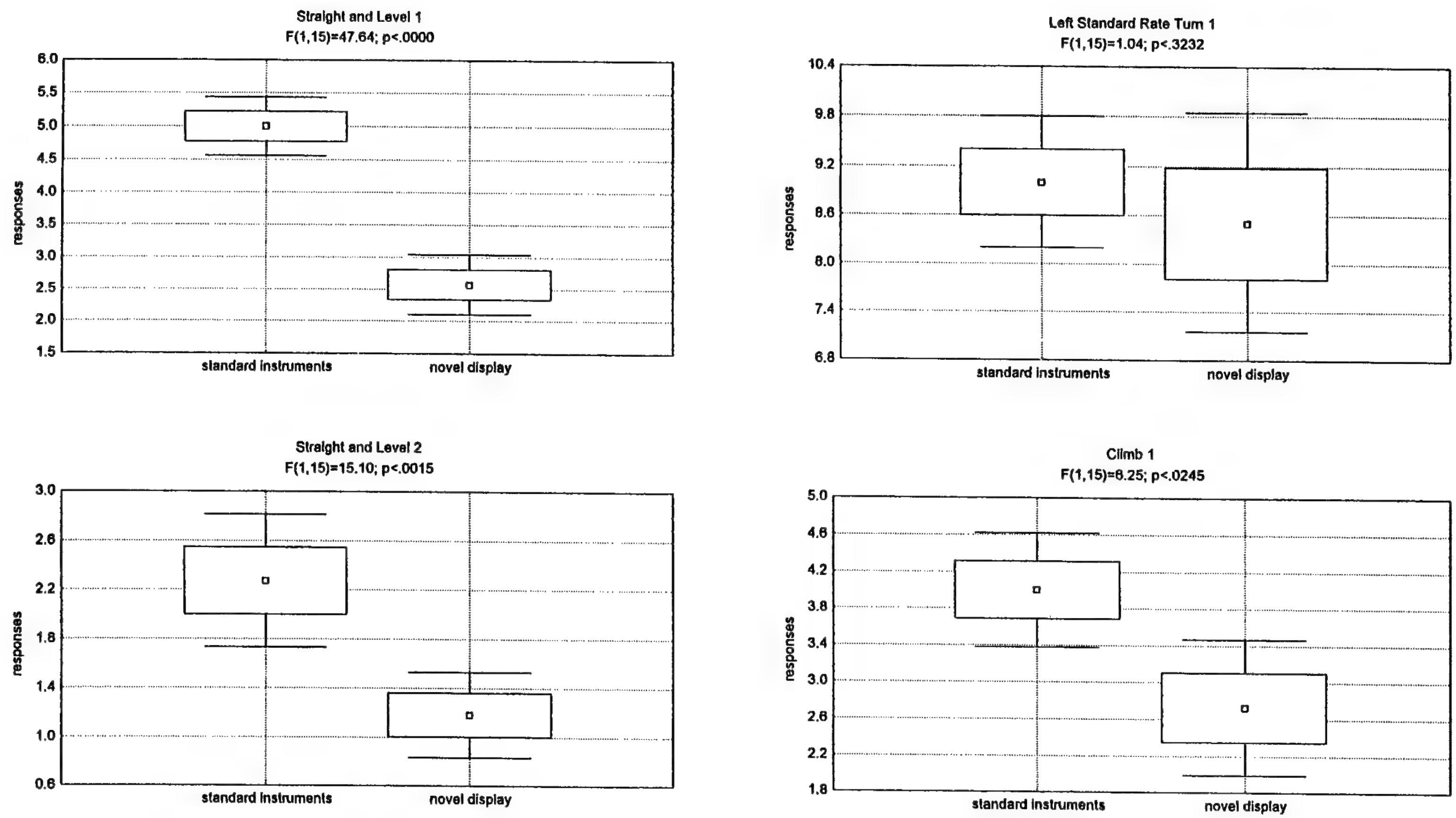


Figure 105. Incorrect responses to presented tones. AFCS ON maneuvers (1). (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

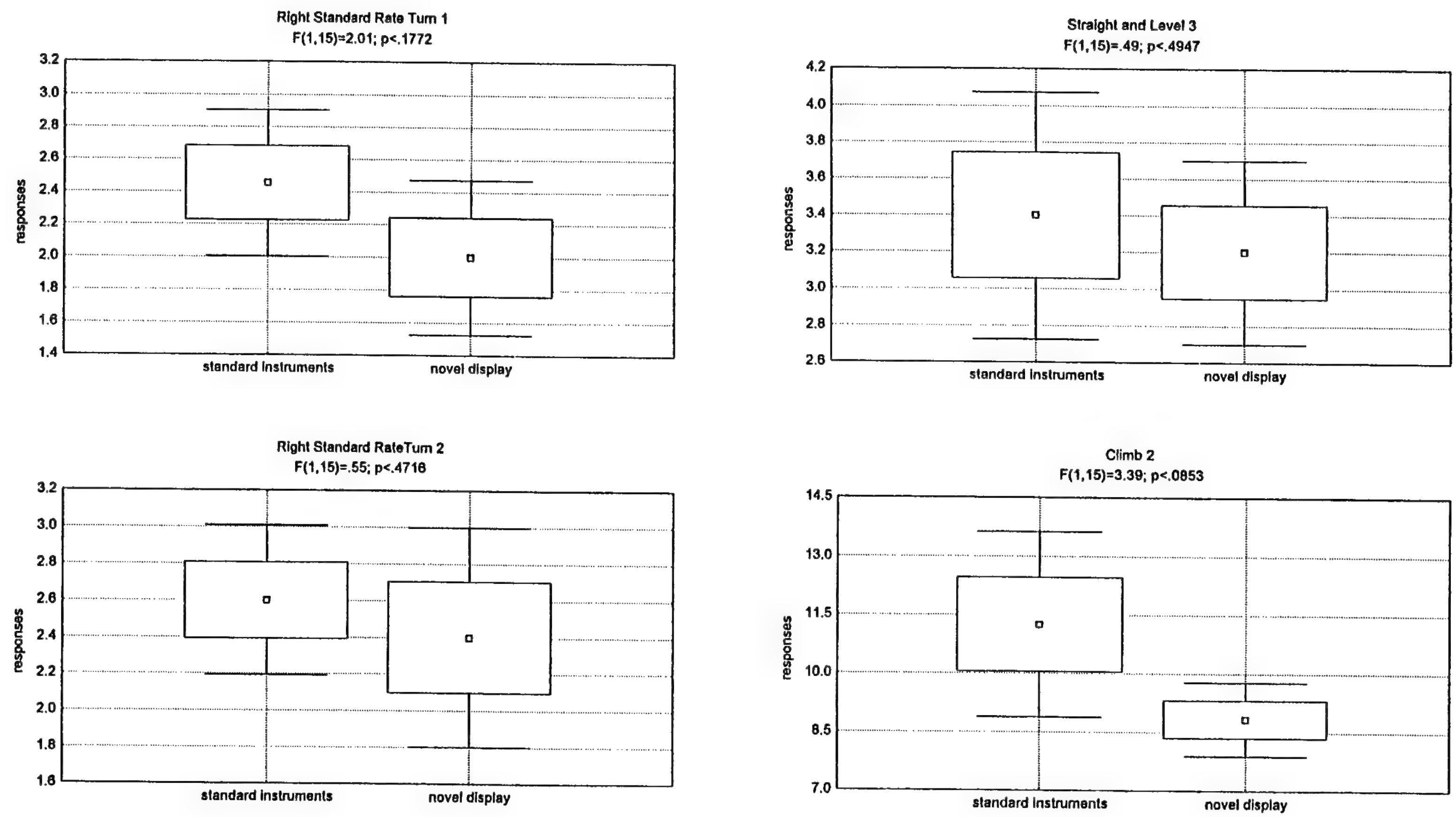


Figure 106. Incorrect responses to presented tones. AFCS ON maneuvers (2). (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

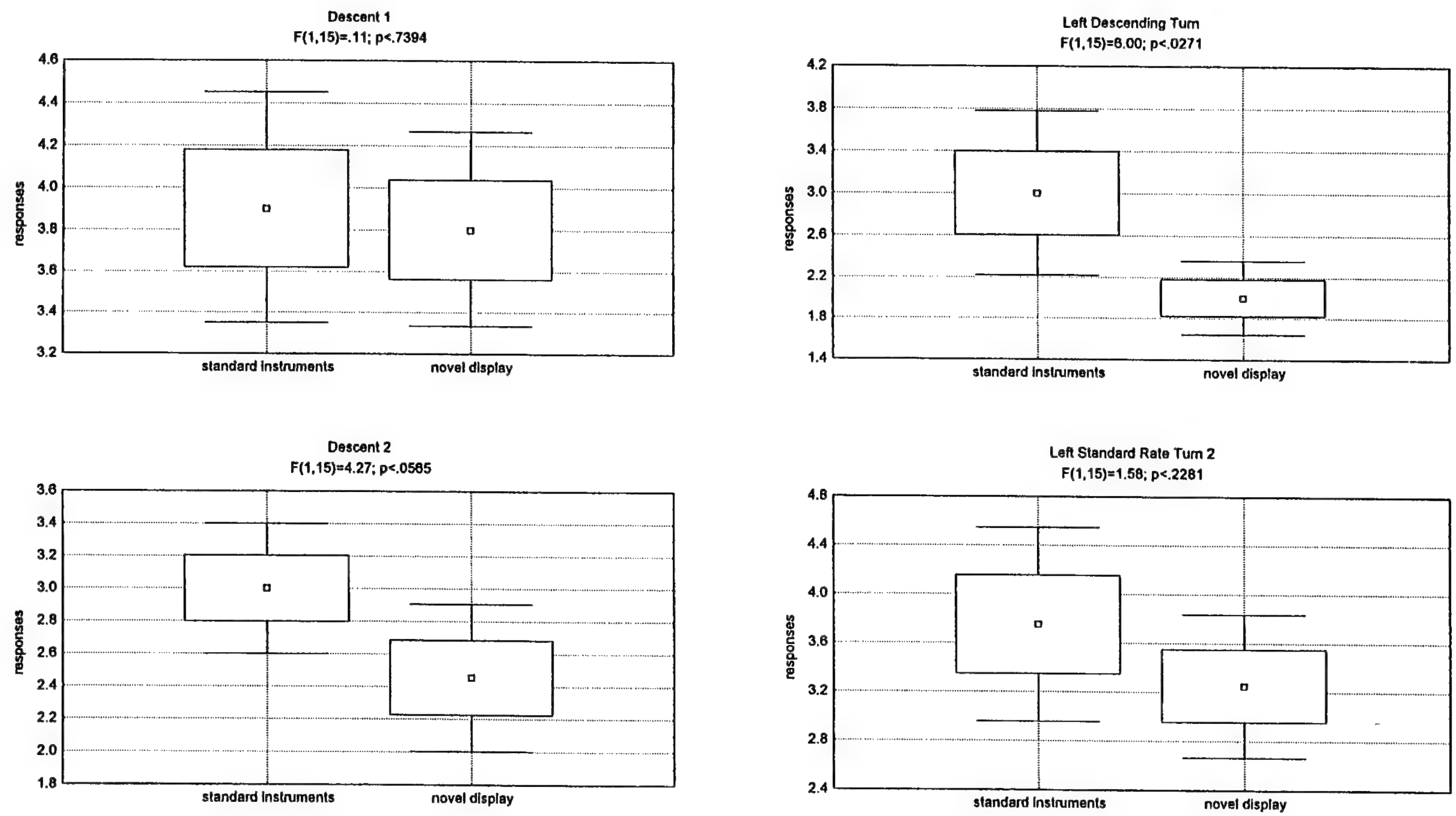


Figure 107. Incorrect responses to presented tones. AFCS OFF maneuvers (1). (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

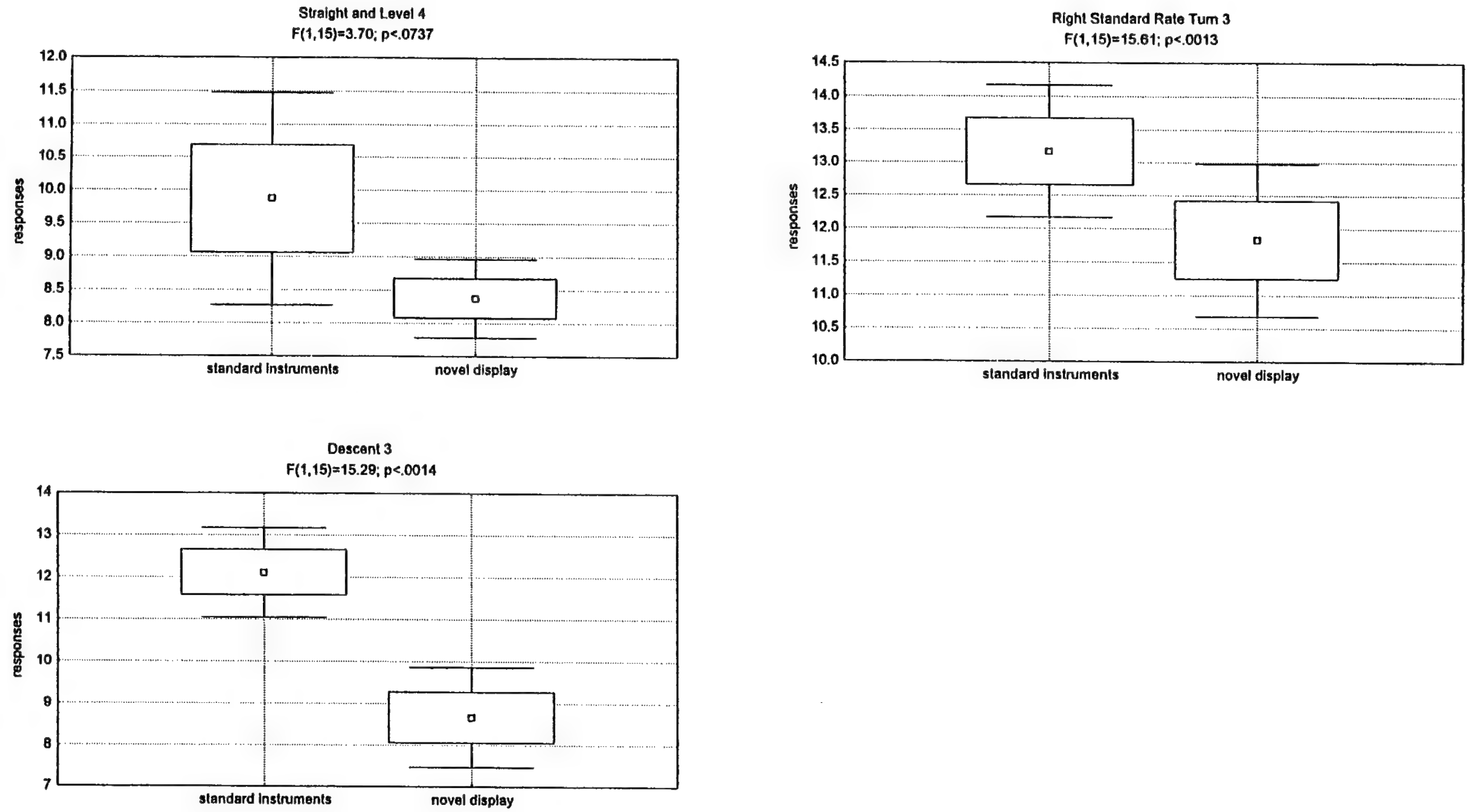


Figure 108. Incorrect responses to presented tones. AFCS OFF maneuvers (2). (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

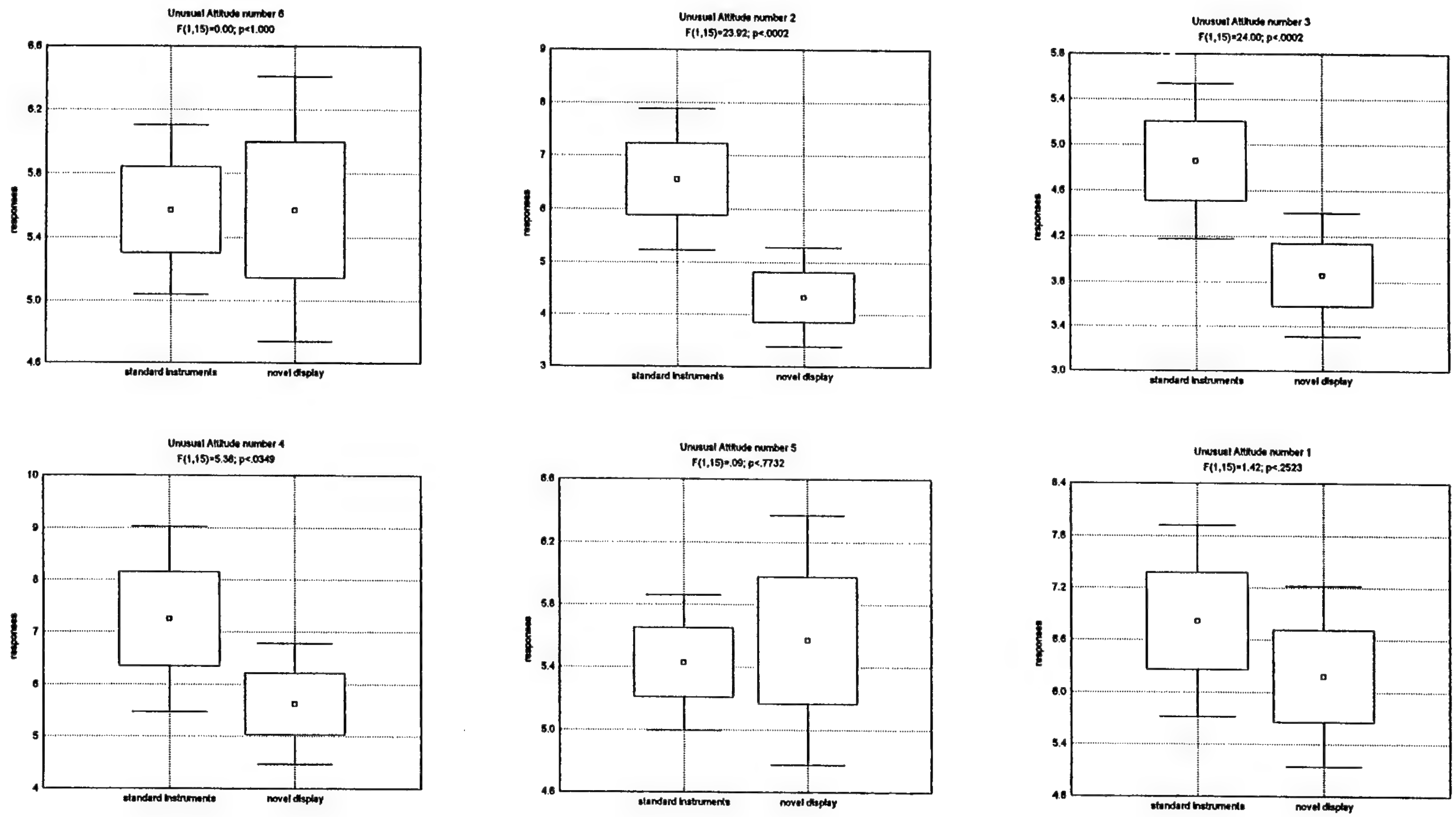


Figure 109. Incorrect responses to presented tones for unusual attitudes.
(Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

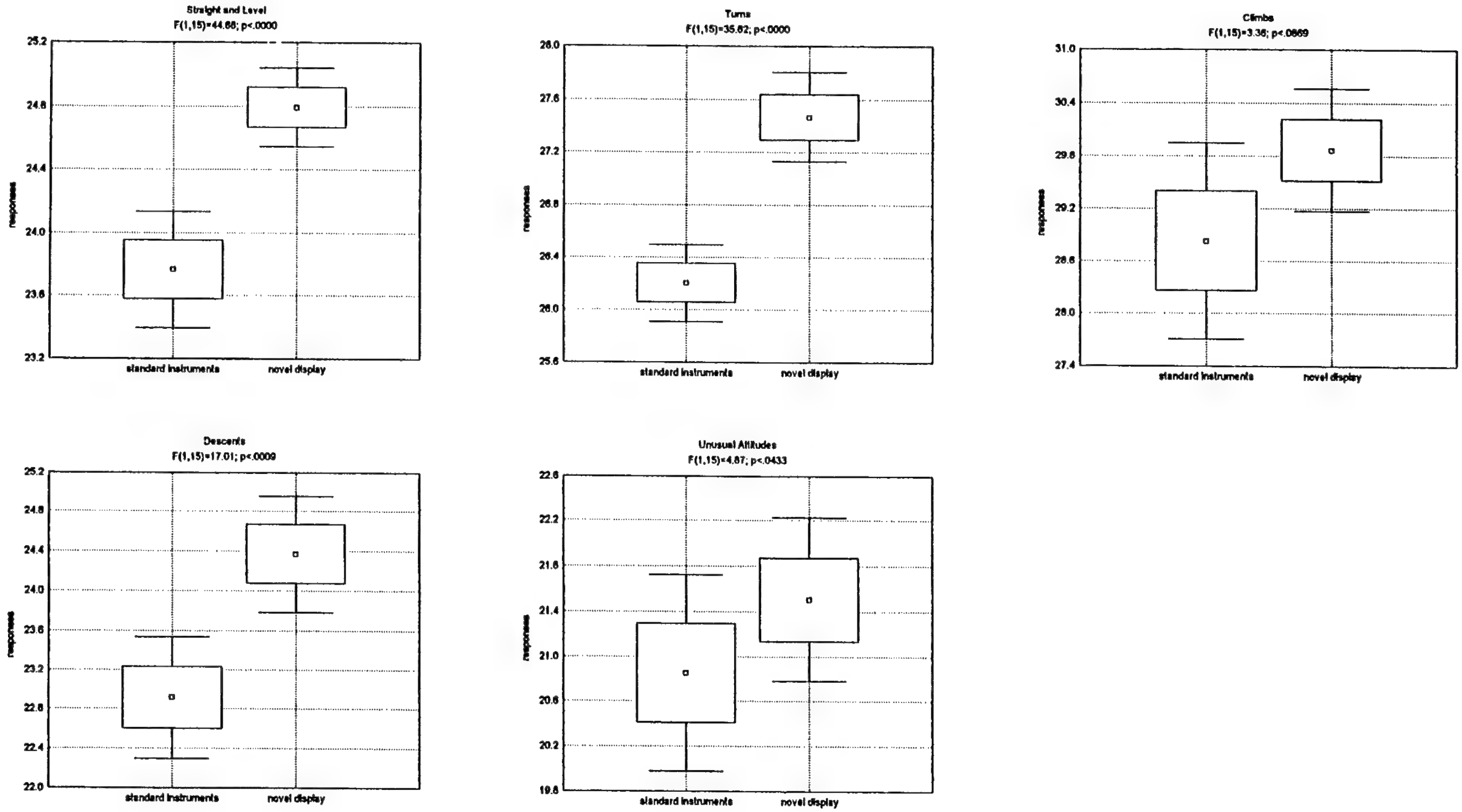


Figure 110. Total responses to presented tones by maneuver type.
(Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

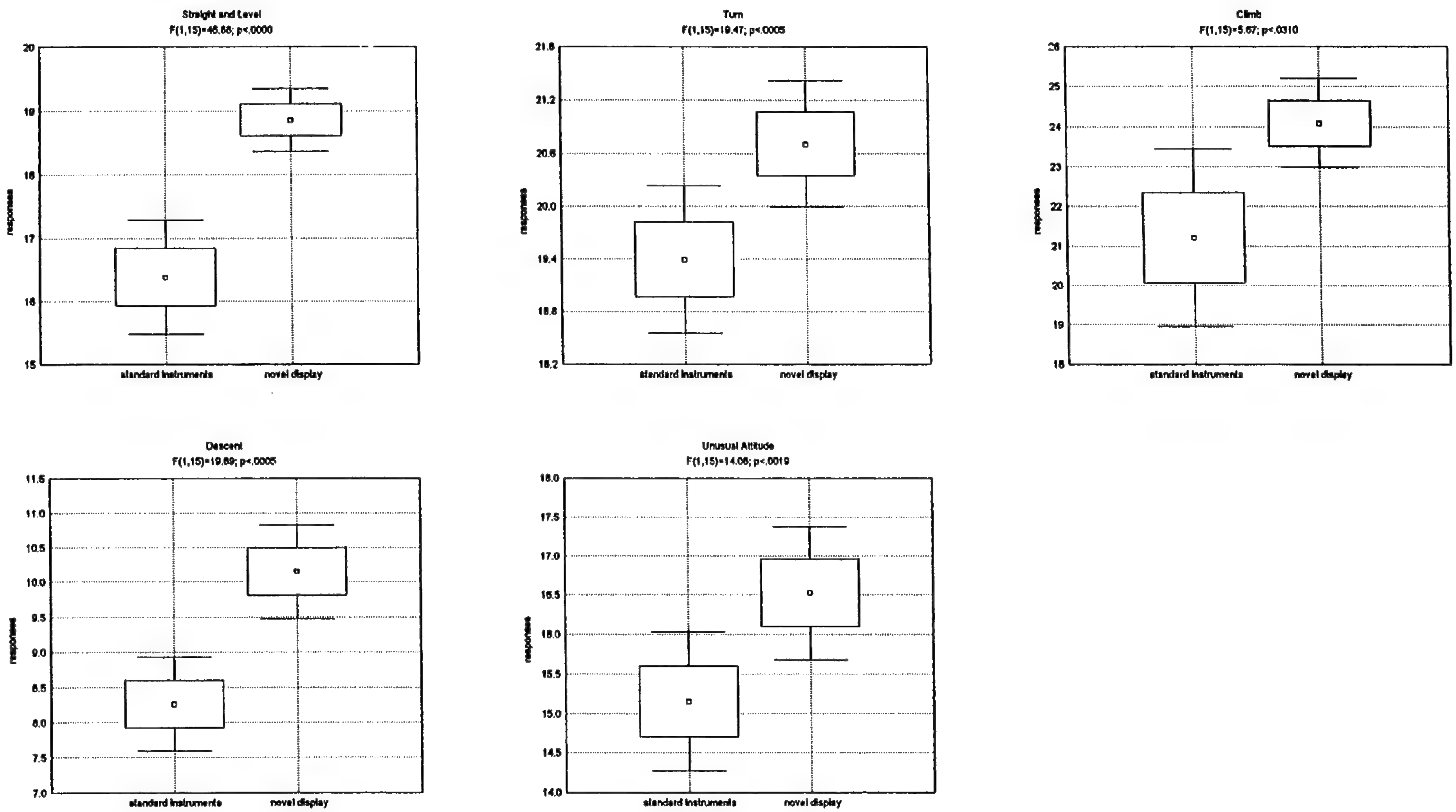


Figure 111. Correct responses to presented tones by maneuver type.
(Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

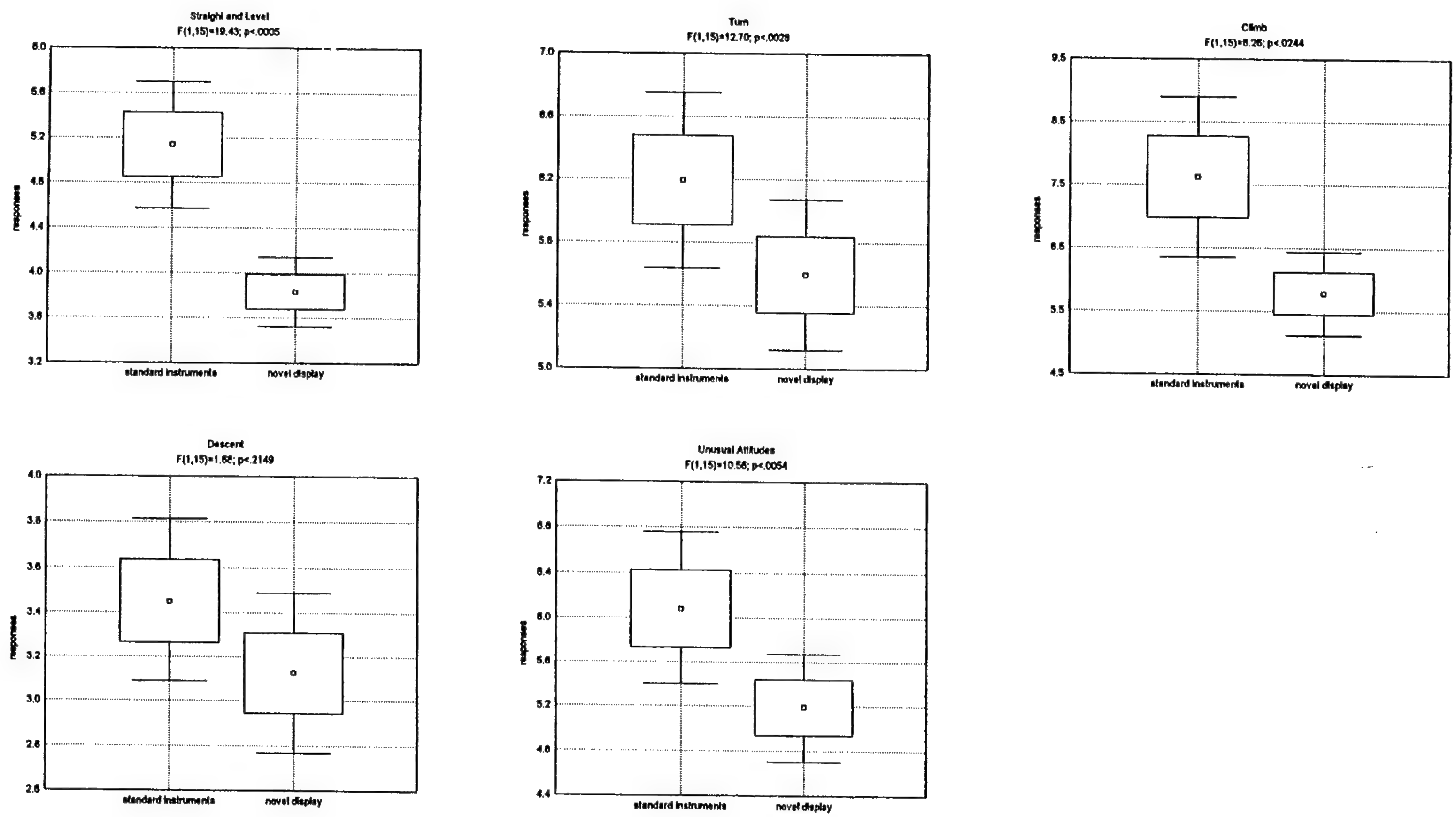


Figure 112. Incorrect responses to presented tones by maneuver type. (Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

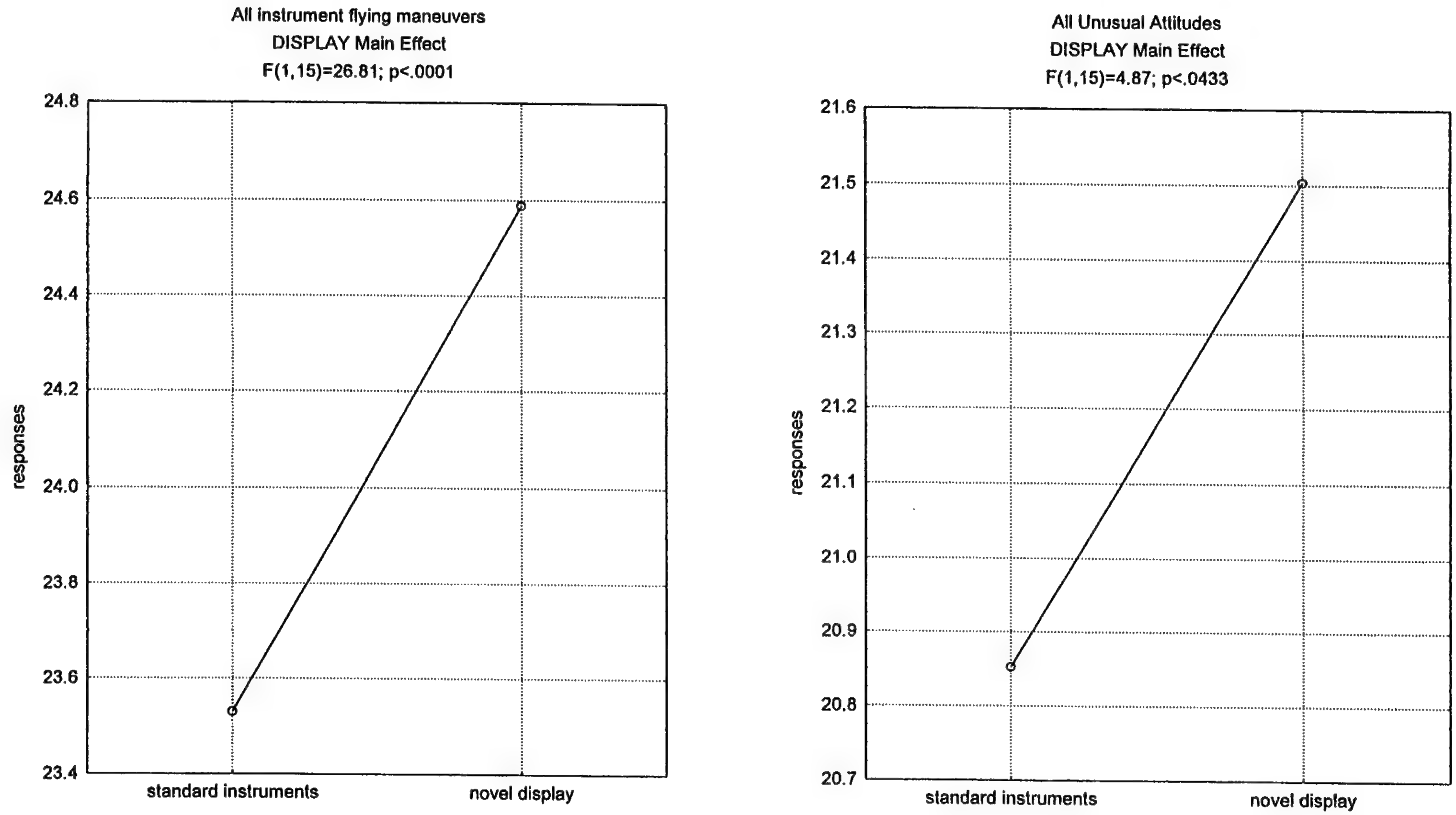


Figure 113. Main effects of total responses to presented tones.

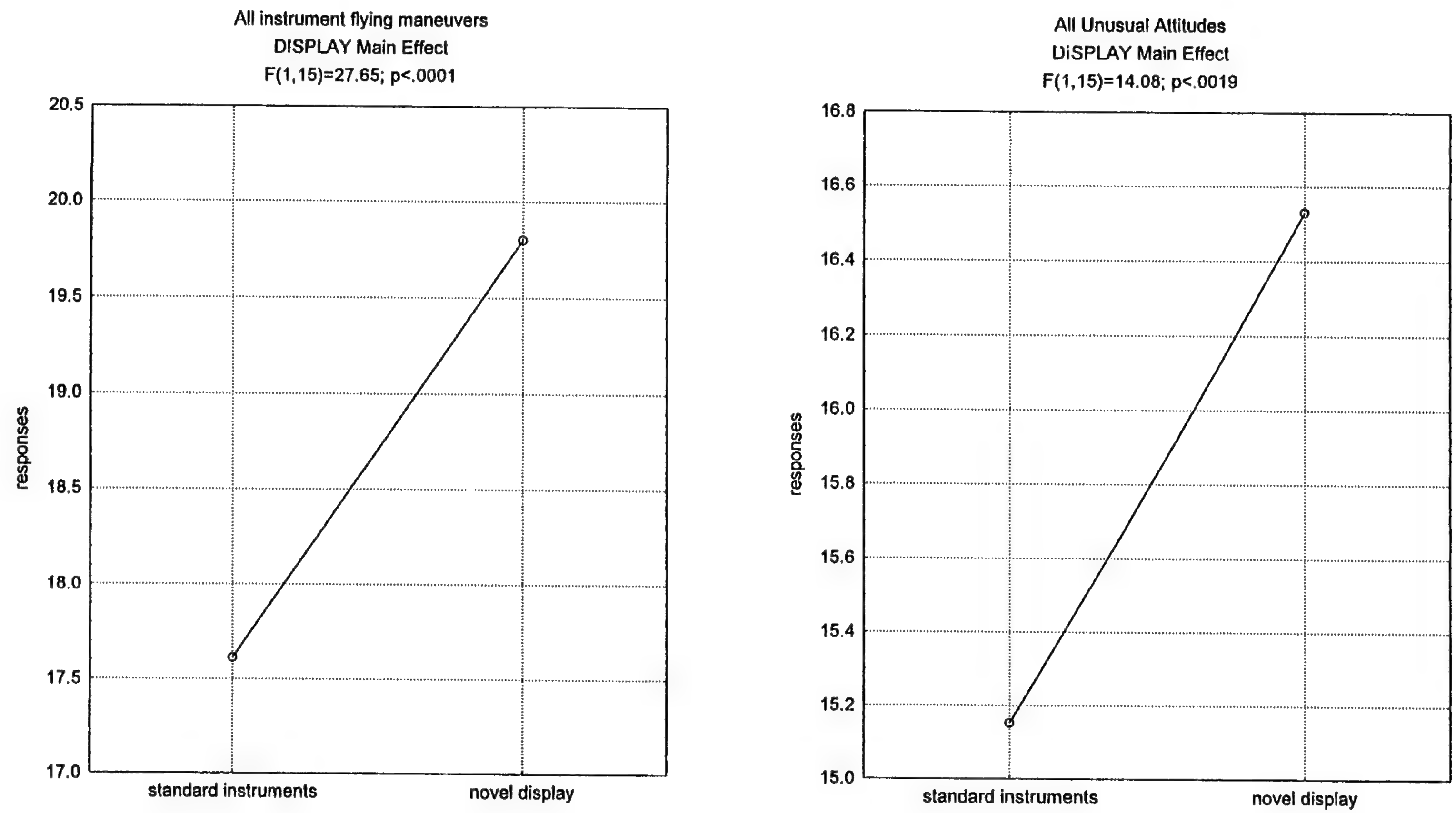
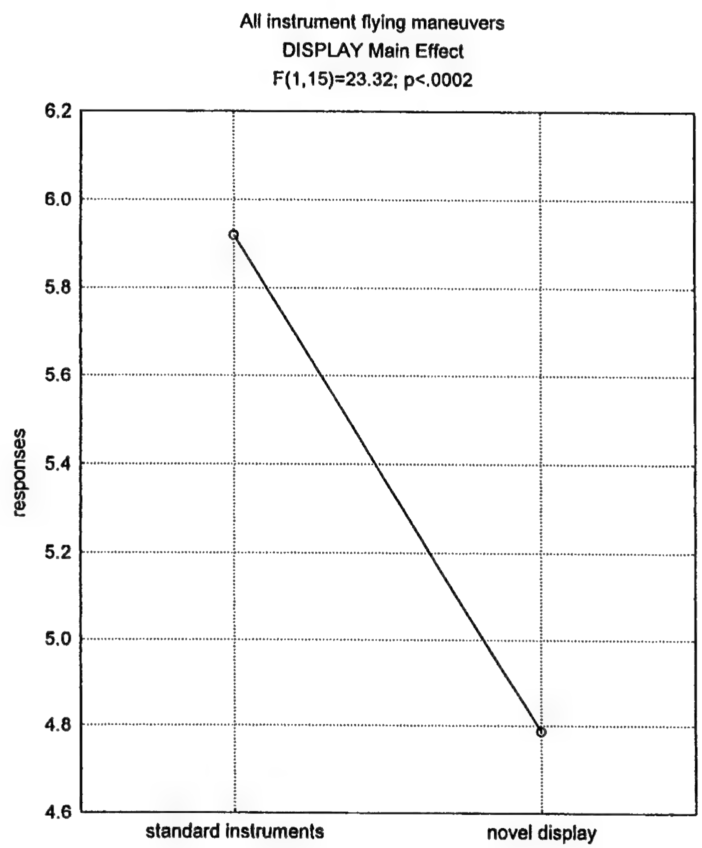


Figure 114. Main effects of correct responses to presented tones.



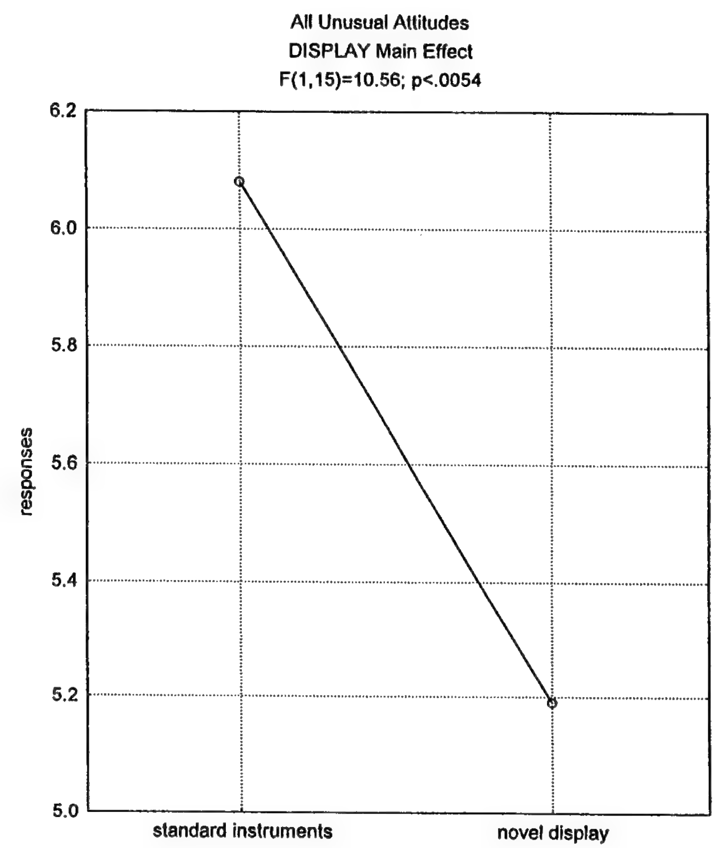
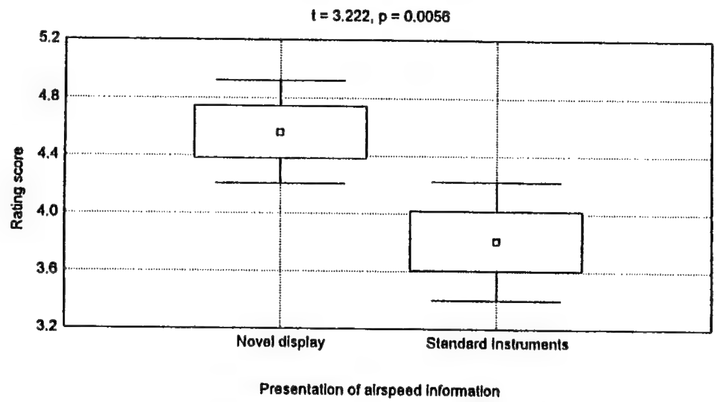
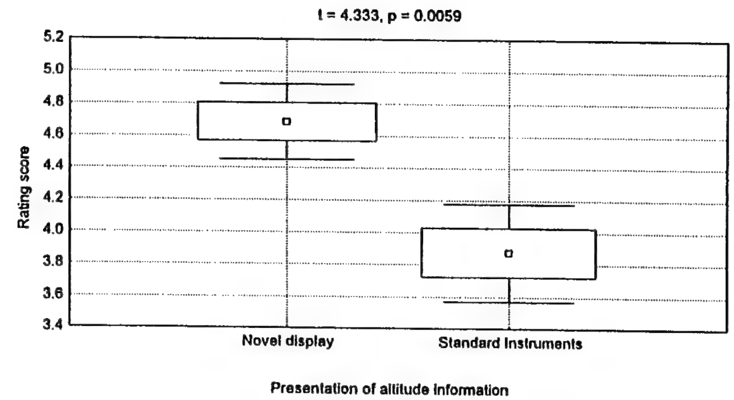
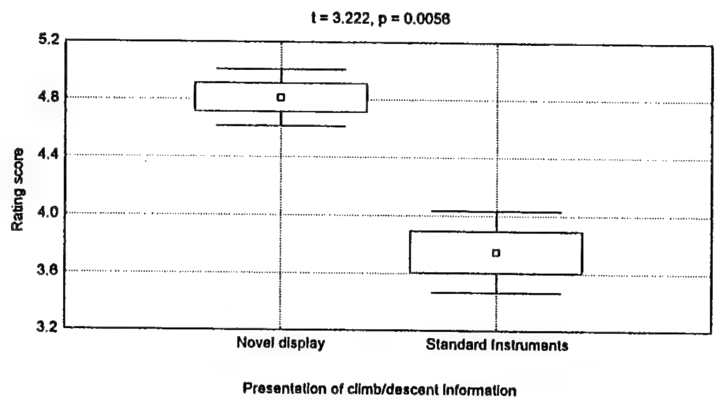


Figure 115. Main effects of incorrect responses to presented tones.





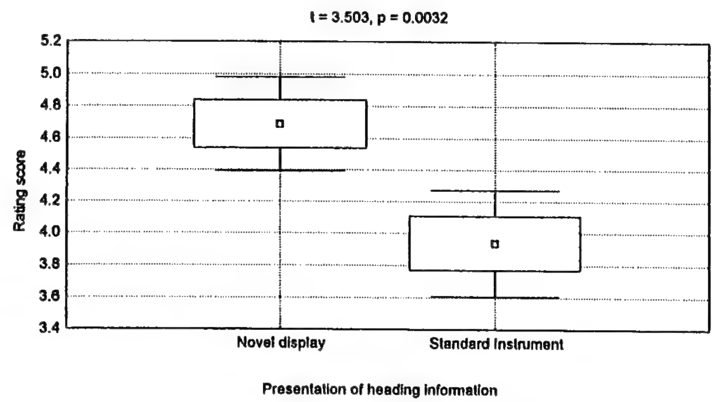


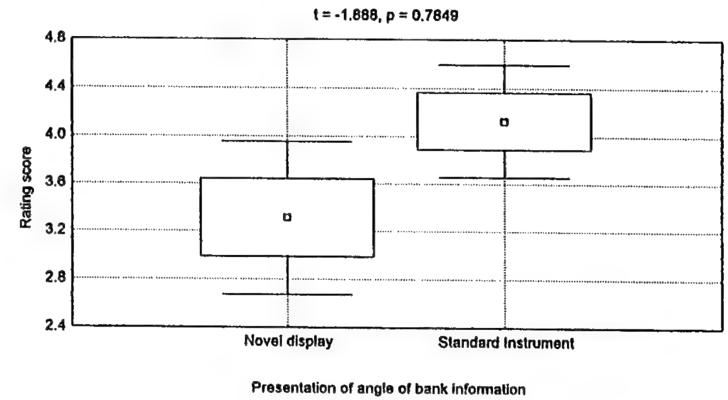
Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

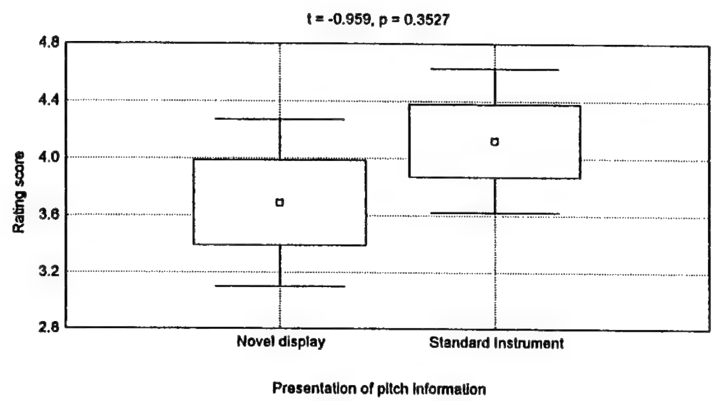
Ratings were as follows:

1 = very difficult
2 = difficult
3 = adequate
4 = easy
5 = very easy

Figure 116. Subjective questionnaire results: presentation of airspeed, altitude and climb/descent information.





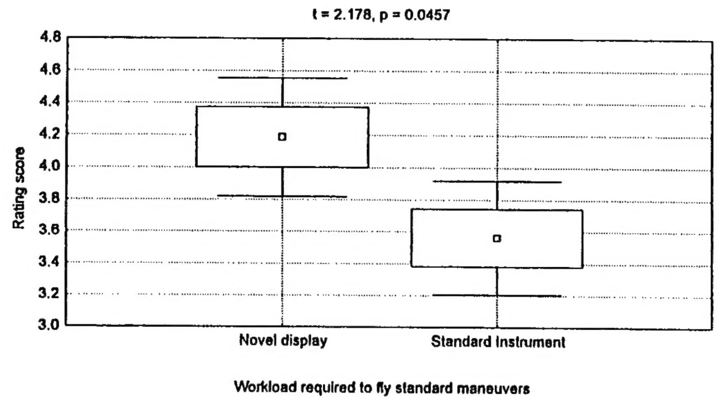


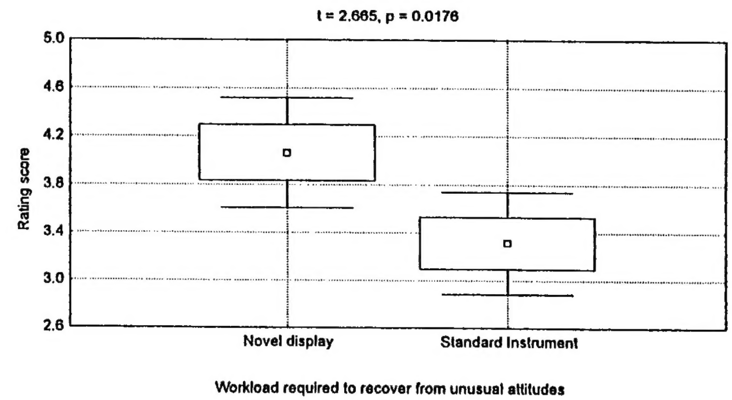
Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

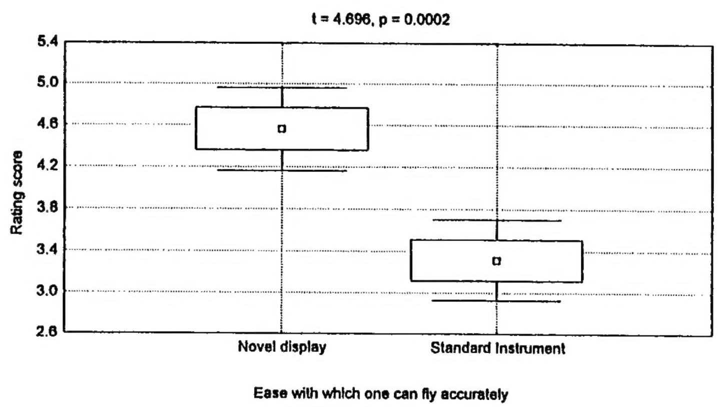
Ratings were as follows:

1 = very difficult
2 = difficult
3 = adequate
4 = easy
5 = very easy

Figure 117. Subjective questionnaire results: presentation of heading, angle of bank and pitch information.





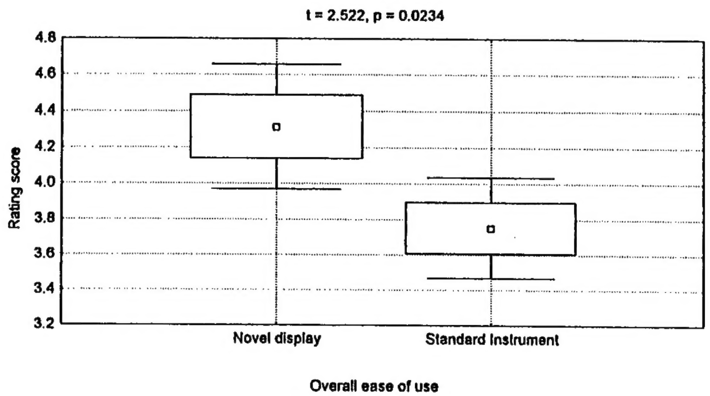


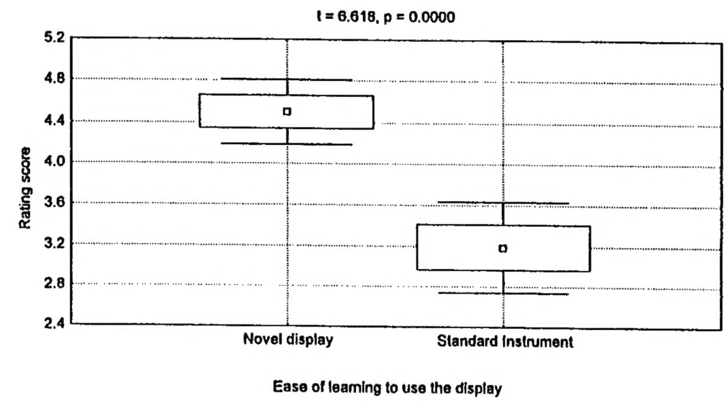
Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

Ratings were as follows:

1 = very difficult
2 = difficult
3 = adequate
4 = easy
5 = very easy

Figure 118. Subjective questionnaire results: aspects of workload and ease of use.





Charts show mean, +/- 1 SE(box), and +/- 1.96 SE (whiskers).

Ratings were as follows:

1 = very difficult
2 = difficult
3 = adequate
4 = easy
5 = very easy

Figure 119. Subjective questionnaire results: overall ease of use and learning.

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